Health Canada Santé Canada

2000 Report on Occupational Radiation Exposures in Canada

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Part 1 of 3

Canada

2000 Report on Occupational Radiation Exposures in Canada

Safe Environments Programme
Healthy Environments and
Consumer Safety Branch

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Abstract

The report provides statistics on occupational radiation exposures for use by regulatory authorities, organizations and private individuals. Out of a total of 125,880 monitored workers, 6 annual doses exceeded the regulatory limit of 50 mSv in 1999. Out of 57 specified job categories, 30 had a smaller annual average in 1999 than in 1998, 14 had a higher average, and 13 had the same average rounded to 0.01 mSv. A new job category was added in 1999 entitled "Tradesman" and therefore a comparison of the averages is not possible at this time. In all categories of workers, from 1997 to 1998, 20 average annual doses went up, 25 went down, and 11 had the same average rounded to 0.01 mSv. The figures reflect a sustained effort in keeping the occupational doses low.

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Introduction

This series of reports provides statistics on occupational radiation exposures of monitored workers in Canada. The statistics are intended to assist regulatory authorities, organizations, and private individuals in comparing incurred occupational radiation exposures with national or provincial/territorial averages and trends in similar occupations. Previous issues of the report can be obtained from the authors[1-5].

The information is based on the data in the National Dose Registry (NDR) maintained by the Radiation Protection Bureau of Health Canada[6]. The Registry is a centralized record-keeping system containing dose information on all monitored workers in Canada. It includes records from the National Dosimetry Services (NDS), as well as data submitted by nuclear power generating stations, Atomic Energy of Canada Ltd., uranium mines, and private dosimeter processing companies. About 80 percent of the records are from the NDS.

Information for input into the NDR is received in a number of different physical forms. Data from the NDS are fed directly from the dosimeter reading stations into a computer, where they are processed, reported and entered into the NDR files. Most other dose records are submitted to the Registry in computer readable form.

The report provides data on the two consecutive years prior to the year in which the data are extracted from the database. The data for the second (i.e. more recent) year will be close to stable at the time of data extraction. Some changes may still occur, for which the most frequent causes are: (1) a high dose to a dosimeter is judged to be non-personal after investigation; (2) a job category of a worker is updated; or, (3) dosimeters or data are returned late. The report therefore contains preliminary data on the second year, and more complete data on the first year.

For a description and a guide to interpretation of the data, the reader is referred to the next section "General comments". The section "Comments specific to this report" has been included to address situations that do not reoccur from year to year.

General Comments

The statistics include doses as they exist in the database at the time they are extracted for analysis, which in the case of this report is 25 July 2000. All NDS doses are assigned to the year in which the dosimeter was issued, even though some of the dosimeters may actually have been worn during part of the subsequent year. As the statistics are determined in the same manner each year, the annual dose figures are based on a 12-month period, though not necessarily the strict calendar year.

Dose records submitted by outside organizations such as nuclear power generating stations, uranium mines, and commercial processors, are included to the extent that they have been received. The doses are representative of the calendar year only if the fourth quarter records have been received by the time of analysis. When statistics are based on partial data, the fact is indicated in the section "Comments specific to this report".

All doses are in International System (SI) units and presented to the nearest hundredth of a millisievert (1 mSv = 100 mrem). For the external whole body doses recorded by the NDS there is a minimum reporting level of 0.2 mSv. Organizations submitting their own doses may have lower reporting levels.

The words "dose" and "exposure" are used interchangeably in this report. Doses of different types of radiation are expressed in mSv and added to give the effective dose stated in the report. The following dose types may be included:

- External whole body gamma.
- External whole body high energy beta.
- External whole body X-ray.
- External whole body neutron.
- Internal whole body tritium, as determined by urinalysis.
- Radon progeny exposures, converted from WLM values (see below).

All types of exposure are given in one total. In Tables 3 and 4, the percentage contribution of radon progeny and tritium components are indicated for occupations related to mining and nuclear power generation, respectively. Skin doses and extremity doses are not included in the report but are recorded in the database.

In the NDR database, radon progeny exposures are expressed in Working Level Months (WLM), which are in most cases calculated by the mines on the basis of area monitoring[7]. In the report the radon progeny exposures are converted to equivalent doses (in mSv). The value used in this report is 5 mSv/WLM, in accordance with the new CNSC regulations[8], which came into force on May 31, 2000.

Job category designations are based on a standard list provided by the Registry and are updated when the Registry is notified. The job category is selected by the organization from a standard list maintained by the NDR. The NDR keeps the most recent job category that an organization submits for a worker in a given year. However, a worker can have records under more than one job category for the same year, if he has been monitored by more than one organization. Some organizations have their own job classifications schemes, and translate them into the Registry's standardized list prior to submission of the records.

In this report, the data are tabulated as follows:

1999: Preliminary analysis

Table 1:

Table 1 gives the annual doses distributions by job category.

1998: Final Analysis

Table 2:

In Table 2, statistics are broken down by job category and province or territory.

Table 3:

Table 3 contains dose distributions broken down by age and sex. In these tables job categories have been grouped into "job sectors".

Table 4:

Table 4 contains various dose statistics broken down by job category. The table also shows the parameters of the lognormal or hybrid lognormal distribution for positive doses, as produced by maximum likelihood estimation. From that information, it is possible to calculate estimates and confidence intervals of statistics of the distribution. For a more detailed discussion the reader is referred to the Appendix.

Table 4 also includes an accumulated dose distribution over the 5 year period 1994-1998 for the workers under the given job category.

Finally, Table 4 contains a histogram that shows the trend in average annual doses over the period 1989-1998.

It should be noted that in the tables, a worker is counted more than once if he (she) works in more than one job category, in more than one province, or in more than on job sector in the same year. For this reason the totals in Tables 2-4 may slightly differ.

Comments specific to this report

Job category information is not provided by all dosimetry companies. In the two previous reports, such unreported job categories in the 1996-1998 data were inferred from earlier information on the same worker. Starting with the 1999 data, these job categories will no longer be inferred, in view of the ever increasing likelihood of job changes. This is expected to be a temporary problem which will disappear when the new regulations[8] are fully implemented.

At the time of extracting the data, we had not received full sets of exposure data for 1999 for all mine sites. This affects some of the statistics in Table 1. This problem will have been corrected in final analysis for 1999 in the next report.

References

1. Sont, W.N. and Ashmore, J.P., "1999 Report on Occupational Radiation Exposures in Canada", Environmental Health Directorate publication 99-EHD-239, Health Canada.

2. Sont, W.N. and Ashmore, J.P., "1998 Report on Occupational Radiation Exposures in Canada", Environmental Health Directorate publication 98-EHD-223, Health Canada.

3. Sont, W.N. and Ashmore, J.P., "1997 Report on Occupational Radiation Exposures in Canada", Environmental Health Directorate publication 97-EHD-213, Health Canada.

4. Sont, W.N. and Ashmore, J.P., "1996 Report on Occupation Radiation Exposures in Canada", Environmental Health Directorate publication 97-EHD-210, Health Canada.

5. Sont, W.N. and Ashmore, J.P., "Occupational radiation exposures in Canada - 1994", Environmental Health Directorate publication 95-EHD-195, Health Canada.

6. Ashmore, J.P. and Grogan, D. "The National Dose Registry for radiation workers in Canada", Radiation Protection Dosimetry 11(2) pp. 95-100 (1985).

7. ICRP publication 65, "Protection against Radon-222 at home and at work.", Annals of the ICRP 23(2), p.4 (1993).

8. Regulations of the Nuclear Safety and Control Act, Canada Gazette, June 21, 2000, part 2. For more information see the web site of the CNSC (formerly AECB): http://www.nuclearsafety.gc.ca/eng/index.htm

9. Kumazawa, S. And Numakunai, T. "A new theoretical analysis of occupational dose distributions indicating the effect of dose limits.", Health Physics 41(3) pp. 465-475 (1981).

Table 1
Breakdown of annual doses by job category for all of Canada

Job Category	Distribution of workers over dose intervals							Number of Workers	Avg. Dose (mSv)	Avg. of Positive Doses
	0 mSv	>0-1 mSv	>1-2 mSv	>2-5 mSv	>5-20 mSv	>20-50 mSv	>50 mSv			
Administration:										
Administrator	330	174	3	0	0	0	0	507	0.13	0.37
Office staff	3109	316	9	4	0	0	0	3438	0.04	0.45
Safety officer	79	18	0	0	0	0	0	97	0.07	0.37
Industry and Research:										
Industrial radiographer	1293	321	164	273	312	45	2	2410	2.67	5.76
Instructor (non-medical)	159	5	2	0	0	0	0	166	0.02	0.59
Instrument technician	1574	246	27	18	5	0	0	1870	0.12	0.79
Laboratory technician (industrial)	2717	400	33	30	5	0	0	3185	0.11	0.73
Nuclear fuel processor	46	29	16	19	10	0	0	120	1.48	2.40
Scientist/engineer (field)	649	478	26	12	9	2	0	1176	0.35	0.77
Scientist/engineer (laboratory)	4099	142	14	2	2	0	0	4259	0.02	0.56
Tradesman	27	1	0	0	0	0	0	28	0.01	0.30
Well logger	343	146	35	23	13	0	0	560	0.50	1.29
Medicine:										
Chiropractor	935	14	4	1	1	0	0	955	0.02	1.01
Dental assistant	9543	99	2	3	2	0	0	9649	0.01	0.54
Dental hygienist	7118	77	0	4	0	0	0	7199	0.01	0.47
Dental therapist/nurse	84	6	0	0	0	0	0	90	0.02	0.25
Dentist	6808	99	2	2	0	1	0	6912	0.01	0.65
Gynaecologist	17	1	0	0	0	0	0	18	0.01	0.20
Laboratory technician (medical)	2492	88	14	13	1	0	1	2609	0.08	1.89
Medical physicist	253	10	1	1	0	0	0	265	0.03	0.60
Medical radiation technologist	9757	627	53	43	1	2	0	10483	0.05	0.68
Nuclear medicine technologist	420	260	206	302	31	0	0	1219	1.35	2.06
Nurse	3353	234	30	6	1	0	0	3624	0.04	0.54
Physician	1421	145	28	16	6	0	0	1616	0.12	0.96
Radiation therapist	876	108	8	6	3	1	0	1002	0.12	0.92
Radiologist (diagnostic)	1327	144	18	9	8	0	0	1506	0.13	1.06
Radiologist (therapeutic)	151	14	0	0	0	0	0	165	0.04	0.45
Veterinarian	3781	191	10	4	1	0	0	3987	0.02	0.48
Veterinary technician	739	27	1	0	0	0	0	767	0.02	0.47
Ward aid/orderly	1386	65	4	6	0	0	0	1461	0.03	0.64

Table 1 (Cont'd)
Breakdown of annual doses by job category for all of Canada

Job Category	Distribution of workers over dose intervals							Number of Workers	Avg. Dose (mSv)	Avg. of Positive Doses
	0 mSv	>0-1 mSv	>1-2 mSv	>2-5 mSv	>5-20 mSv	>20-50 mSv	>50 mSv			
Nuclear Power:										
Reactor - administration	3615	584	139	109	50	0	0	4497	0.24	1.20
Reactor - chemical and radiation control	92	156	31	41	38	0	0	358	1.58	2.13
Reactor - construction	756	314	126	176	226	0	0	1598	1.82	3.46
Reactor - control technician	55	36	17	18	7	0	0	133	1.22	2.08
Reactor - electrical maintenance	396	282	129	135	43	0	0	985	1.04	1.73
Reactor - fuel handling	1	9	1	11	23	0	0	45	6.31	6.46
Reactor - general maintenance	771	281	62	86	100	0	0	1300	1.03	2.54
Reactor - health physics	46	18	3	9	0	0	0	76	0.50	1.27
Reactor - industrial radiographer	5	1	3	5	3	0	0	17	2.42	3.43
Reactor - mechanical maintenance	345	303	139	227	272	0	0	1286	2.53	3.46
Reactor - operations	676	725	222	185	120	0	0	1928	1.15	1.77
Reactor - scientific/professional	1147	221	47	69	59	0	0	1543	0.54	2.12
Reactor - training	68	11	5	2	7	0	0	93	0.83	3.10
Reactor - visitor	2357	110	45	67	87	1	0	2667	0.40	3.46
Uranium Mining:										
Uranium mine electrician	3	13	1	0	0	0	0	17	0.29	0.36
Uranium mine mill maintenance	10	114	16	2	0	0	0	142	0.57	0.62
Uranium mine mill worker	24	125	19	10	0	0	0	178	0.66	0.76
Uranium mine nurse	19	3	0	0	0	0	0	22	0.03	0.25
Uranium mine office staff	83	73	0	0	0	0	0	156	0.10	0.21
Uranium mine support worker	51	212	74	10	0	0	0	347	0.61	0.71
Uranium mine surface maintenance	59	120	4	0	0	0	0	183	0.22	0.32
Uranium mine surface miner	33	39	0	0	0	0	0	72	0.08	0.15
Uranium mine surface personnel	70	88	7	1	0	0	0	166	0.23	0.39
Uranium mine surface support worker	88	103	4	1	0	0	0	196	0.13	0.24
Uranium mine underground maintenance	15	100	19	5	0	0	0	139	0.57	0.64
Uranium mine underground miner	17	134	119	43	8	0	0	321	1.33	1.41
Uranium mine underground personnel	33	80	19	5	0	0	0	137	0.53	0.70
Uranium mine visitor	78	116	0	0	0	0	0	194	0.09	0.16
Miscellaneous/Unknown										
Miscellaneous/unknown	31292	9426	888	697	297	20	3	42623	0.24	0.89

Table 2
Number of workers (top) and average whole body dose in mSv (bottom) by job category and province/territory

Job Sector and Category	Nfld.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	N.W.T.	Yukon	Canada
Administration													
Administrator	3	0	9	3	50	383	17	2	30	29	0	0	526
	0.00	0.00	0.06	0.00	0.02	0.16	0.00	0.00	0.01	0.02	0.00	0.00	0.12
Office staff	33	5	75	63	655	1923	233	67	171	261	10	0	3496
	0.01	0.00	0.01	0.02	0.03	0.07	0.03	0.03	0.03	0.03	0.04	0.00	0.05
Safety officer	3	1	9	2	18	33	12	2	3	13	0	0	96
	0.00	0.00	0.30	0.00	0.03	0.26	0.00	0.00	0.57	0.29	0.00	0.00	0.18
OVERALL	**39**	**6**	**93**	**68**	**723**	**2339**	**262**	**71**	**204**	**303**	**10**	**0**	**4118**
	0.01	**0.00**	**0.04**	**0.02**	**0.03**	**0.08**	**0.03**	**0.02**	**0.03**	**0.04**	**0.04**	**0.00**	**0.06**
Industry and Research													
Industrial radiographer	33	0	85	83	376	636	31	158	927	183	0	3	2515
	1.38	0.00	1.37	1.26	1.86	2.04	0.74	1.72	4.57	1.23	0.00	0.00	2.79
Instructor (non-medical)	11	3	27	3	14	58	8	4	15	23	2	0	168
	0.00	0.00	0.06	0.00	0.01	0.06	0.00	0.10	0.01	0.01	0.00	0.00	0.04
Instrument technician	79	1	55	48	421	779	58	26	162	167	0	0	1796
	0.03	0.20	0.13	0.40	0.62	0.26	0.05	0.11	0.29	0.15	0.00	0.00	0.32
Laboratory technician	58	11	89	42	846	1572	234	228	488	251	0	0	3819
(industrial)	0.12	0.09	0.08	0.06	0.15	0.18	0.08	0.01	0.09	0.37	0.00	0.00	0.16
Nuclear fuel processor	0	0	0	0	1	168	1	0	2	2	0	0	174
	0.00	0.00	0.00	0.00	0.00	4.20	0.00	0.00	0.25	0.00	0.00	0.00	4.06
Scientist engineer (field)	9	0	31	43	66	917	15	49	90	101	2	0	1323
	0.00	0.00	0.19	0.26	0.41	0.30	0.18	0.09	0.51	0.10	0.00	0.00	0.29
Scientist/engineer	117	3	125	23	1708	1436	154	149	199	825	0	0	4739
(laboratory)	0.03	0.07	0.04	0.07	0.03	0.06	0.02	0.03	0.07	0.06	0.00	0.00	0.05
Well logger	3	0	1	0	1	0	0	36	802	15	1	0	859
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.46	0.15	0.00	0.00	0.43
OVERALL	**310**	**18**	**413**	**242**	**3433**	**5566**	**501**	**650**	**2685**	**1567**	**5**	**3**	**15393**
	0.19	**0.08**	**0.35**	**0.58**	**0.34**	**0.51**	**0.10**	**0.44**	**1.77**	**0.26**	**0.00**	**0.00**	**0.64**
Medicine													
Chiropractor	1	0	1	3	422	311	63	8	112	26	0	0	947
	0.00	0.00	0.00	0.00	0.09	0.03	0.04	0.00	0.02	0.06	0.00	0.00	0.06
Dental assistant	106	34	244	131	1822	4487	596	332	598	612	18	6	8986
	0.02	0.01	0.02	0.03	0.01	0.01	0.01	0.02	0.02	0.01	0.00	0.00	0.01
Dental hygienist	46	18	163	91	2283	3030	445	155	289	340	11	3	6874
	0.05	0.00	0.01	0.02	0.01	0.02	0.00	0.00	0.01	0.01	0.06	0.00	0.01
Dental therapist/nurse	1	0	0	0	8	17	11	37	0	8	5	9	96
	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.03	0.06	0.00	0.01
Dentist	90	10	146	90	2441	2848	535	127	255	263	21	3	6829
	0.04	0.00	0.01	0.03	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.00	0.01
Gynaecologist	1	0	1	0	3	13	6	0	1	3	0	0	28
	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.11
Laboratory technician	37	1	143	2	1017	1064	133	120	242	323	0	0	3082
(medical)	0.56	0.00	0.03	0.00	0.07	0.12	0.02	0.06	0.06	0.06	0.00	0.00	0.09
Medical physicist	3	0	10	7	87	85	13	10	11	57	1	0	284
	0.13	0.00	0.14	0.10	0.08	0.11	0.14	4.24	0.00	0.02	0.00	0.00	0.23
Medical radiation	288	70	259	355	2627	4312	638	606	1243	1327	27	11	11763
technologist	0.10	0.12	0.11	0.12	0.07	0.11	0.06	0.07	0.12	0.08	0.03	0.14	0.09
Nuclear medicine	20	4	47	33	464	551	74	24	75	151	0	0	1443
technologist	2.00	0.58	1.78	1.09	1.82	1.34	0.93	1.92	1.38	0.72	0.00	0.00	1.43

Table 2 (Cont'd)
Number of workers (top) and average whole body dose in mSv (bottom) by job category and province/territory

Job Sector and Category	Nfld.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	N.W.T.	Yukon	Canada
Medicine (cont'd)													
Nurse	154	4	174	130	1032	2227	176	86	131	278	125	65	4582
	0.51	0.25	0.08	0.09	0.06	0.32	0.02	0.07	0.16	0.06	0.01	0.08	0.20
Physician	35	5	61	32	632	809	62	51	136	178	6	3	2010
	0.25	0.14	0.09	0.24	0.18	0.24	0.72	0.55	0.15	0.24	0.07	0.10	0.24
Radiation therapist	11	0	39	26	248	402	56	56	60	177	0	0	1075
	0.27	0.00	0.15	0.06	0.15	0.13	0.05	0.09	0.06	0.21	0.00	0.00	0.14
Radiologist (diagnostic)	48	7	44	52	512	663	69	44	134	218	1	0	1792
	0.15	0.16	0.25	0.11	0.10	0.19	0.08	0.07	0.16	0.13	0.00	0.00	0.15
Radiologist (therapeutic)	4	0	3	8	47	44	11	4	10	21	0	0	152
	0.10	0.00	0.20	0.03	0.14	0.05	0.03	0.00	0.01	0.41	0.00	0.00	0.12
Veterinarian	33	36	180	77	694	1354	231	180	709	698	0	7	4199
	0.08	0.17	0.03	0.82	0.03	0.05	0.02	0.04	0.04	0.03	0.00	0.00	0.06
Veterinary technician	2	1	11	1	35	50	7	2	21	40	0	0	170
	0.00	0.00	0.02	0.00	0.01	0.04	0.00	0.00	0.01	0.03	0.00	0.00	0.02
Ward aid/orderly	18	14	20	45	839	315	93	29	39	124	5	0	1541
	0.08	0.24	0.12	1.45	0.05	0.22	0.04	0.17	0.04	0.03	0.04	0.00	0.13
OVERALL	**898**	**204**	**1546**	**1083**	**15213**	**22582**	**3219**	**1871**	**4066**	**4844**	**220**	**107**	**55853**
	0.22	**0.11**	**0.11**	**0.22**	**0.10**	**0.12**	**0.06**	**0.11**	**0.09**	**0.09**	**0.02**	**0.06**	**0.11**
Nuclear Power													
Reactor - administration	0	0	0	163	344	4572	0	0	0	0	0	0	5079
	0.00	0.00	0.00	0.07	0.25	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.21
Reactor - chemical and radiation control	0	0	0	29	36	300	0	0	0	0	0	0	365
	0.00	0.00	0.00	0.32	0.91	1.58	0.00	0.00	0.00	0.00	0.00	0.00	1.41
Reactor - construction	0	0	0	0	55	1093	0	0	0	0	0	0	1148
	0.00	0.00	0.00	0.00	0.35	1.66	0.00	0.00	0.00	0.00	0.00	0.00	1.60
Reactor - control technician	0	0	0	0	116	1	0	0	0	0	0	0	117
	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.49
Reactor - electrical maintenance	0	0	0	86	45	824	0	0	0	0	0	0	955
	0.00	0.00	0.00	0.65	5.45	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.95
Reactor - fuel handling	0	0	0	46	9	2	0	0	0	0	0	0	57
	0.00	0.00	0.00	5.06	3.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.57
Reactor - general maintenance	0	0	0	212	96	839	0	0	0	0	0	0	1147
	0.00	0.00	0.00	0.62	2.89	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.90
Reactor - health physics	0	0	0	37	6	15	0	0	0	0	0	0	58
	0.00	0.00	0.00	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51
Reactor - industrial radiographer	0	0	0	0	0	8	0	0	0	0	0	0	8
	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.80
Reactor - mechanical maintenance	0	0	0	164	207	850	0	0	0	0	0	0	1221
	0.00	0.00	0.00	0.94	2.51	2.26	0.00	0.00	0.00	0.00	0.00	0.00	2.13
Reactor - operations	0	0	0	100	116	1696	0	0	0	0	0	0	1912
	0.00	0.00	0.00	0.37	1.45	1.27	0.00	0.00	0.00	0.00	0.00	0.00	1.24
Reactor - scientific/ professional	0	0	0	338	147	952	0	0	0	0	0	0	1437
	0.00	0.00	0.00	0.32	0.70	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.53
Reactor - training	0	0	0	34	19	5	0	0	0	0	0	0	58
	0.00	0.00	0.00	0.65	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60
Reactor - visitor	0	0	0	0	55	610	0	0	0	0	0	0	665
	0.00	0.00	0.00	0.00	0.99	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.52
OVERALL	**0**	**0**	**0**	**1209**	**1251**	**11767**	**0**	**0**	**0**	**0**	**0**	**0**	**14227**
	0.00	**0.00**	**0.00**	**0.65**	**1.37**	**0.80**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.84**

Table 2 (cont'd)
Number of workers (top) and average whole body dose in mSv (bottom) by job category and province/territory

Job Sector and Category	Nfld.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	N.W.T.	Yukon	Canada
Uranium Mining													
Uranium mine electrician	0	0	0	0	0	0	0	9	0	0	0	0	9
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.16
Uranium mine mill maintenance	0	0	0	0	0	0	0	161	0	0	0	0	161
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.09	0.00	0.00	0.00	0.00	1.09
Uranium mine mill workers	0	0	0	0	0	4	0	208	0	0	0	0	212
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	1.37
Uranium mine nurse	0	0	0	0	0	0	0	17	0	0	0	0	17
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.04
Uranium mine office staff	0	0	0	0	0	0	0	160	0	0	0	0	160
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.17
Uranium mine support worker	0	0	0	0	0	2	0	288	0	0	0	0	290
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.28	0.00	0.00	0.00	0.00	1.28
Uranium mine surface maintenance	0	0	0	0	0	3	0	173	0	0	0	0	176
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.36
Uranium mine surface miner	0	0	0	0	0	0	0	96	0	0	0	0	96
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.80
Uranium mine surface personnel	0	0	0	0	0	2	0	124	0	0	0	0	126
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.37
Uranium mine surface support worker	0	0	0	0	0	19	0	274	0	0	0	0	293
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.00	0.00	0.00	0.00	0.36
Uranium mine underground maintenance	0	0	0	0	0	1	0	138	0	0	0	0	139
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.00	0.00	0.00	0.93
Uranium mine underground miner	0	0	0	0	0	1	0	361	0	0	0	0	362
	0.00	0.00	0.00	0.00	0.00	0.20	0.00	1.98	0.00	0.00	0.00	0.00	1.97
Uranium mine underground personnel	0	0	0	0	0	37	0	314	0	0	0	0	351
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.54
Uranium mine visitor	0	0	0	0	0	0	0	295	0	0	0	0	295
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.05
OVERALL	**0**	**0**	**0**	**0**	**0**	**69**	**0**	**2618**	**0**	**0**	**0**	**0**	**2687**
	0.00	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.00**	**0.84**	**0.00**	**0.00**	**0.00**	**0.00**	**0.82**

Table 3
Dose distribution broken down by job sector, age and sex.

Job Sector	Age	Statistic	Sex			
			Male	Female	Unknown	Overall
Administration	Below 25	Number of Workers	8	209	1	218
		Average dose (mSv)	0.00	0.01	0.00	0.01
	25-34	Number of Workers	47	912	2	961
		Average dose (mSv)	0.11	0.02	0.00	0.03
	35-44	Number of Workers	163	1262	2	1427
		Average dose (mSv)	0.25	0.04	0.00	0.07
	45-54	Number of Workers	189	913	1	1103
		Average dose (mSv)	0.23	0.06	0.00	0.09
	55-up	Number of Workers	79	264	3	346
		Average dose (mSv)	0.13	0.03	0.00	0.06
	Unknown	Number of Workers	18	42	0	60
		Average dose (mSv)	0.27	0.07	0.00	0.13
	Overall	**Number of Workers**	**504**	**3602**	**9**	**4115**
		Average dose (mSv)	**0.21**	**0.04**	**0.00**	**0.06**
Industry and Research	Below 25	Number of Workers	726	439	5	1170
		Average dose (mSv)	1.70	0.06	0.30	1.08
	25-34	Number of Workers	3050	1379	11	4440
		Average dose (mSv)	1.12	0.11	0.00	0.81
	35-44	Number of Workers	4030	1115	8	5153
		Average dose (mSv)	0.66	0.12	0.03	0.54
	45-54	Number of Workers	2709	520	3	3232
		Average dose (mSv)	0.68	0.11	3.37	0.59
	55-up	Number of Workers	934	117	9	1060
		Average dose (mSv)	0.31	0.19	0.02	0.29
	Unknown	Number of Workers	179	20	1	200
		Average dose (mSv)	0.30	0.02	0.00	0.27
	Overall	**Number of Workers**	**11628**	**3590**	**37**	**15255**
		Average dose (mSv)	**0.82**	**0.11**	**0.32**	**0.65**
Medicine	Below 25	Number of Workers	287	3378	5	3670
		Average dose (mSv)	0.15	0.06	0.00	0.07
	25-34	Number of Workers	2983	14295	19	17297
		Average dose (mSv)	0.17	0.09	0.03	0.11
	35-44	Number of Workers	5033	13060	16	18109
		Average dose (mSv)	0.16	0.11	0.00	0.13
	45-54	Number of Workers	4484	7373	7	11864
		Average dose (mSv)	0.12	0.11	0.06	0.11
	55-up	Number of Workers	2396	1370	31	3797
		Average dose (mSv)	0.09	0.10	0.02	0.09
	Unknown	Number of Workers	323	333	0	656
		Average dose (mSv)	0.07	0.08	0.00	0.08
	Overall	**Number of Workers**	**15506**	**39809**	**78**	**55393**
		Average dose (mSv)	**0.14**	**0.10**	**0.02**	**0.11**

Table 3 (Cont'd)
Dose distribution broken down by job sector, age and sex.

			Sex			
Job Sector	Age	Statistic	Male	Female	Unknown	Overall
Nuclear Power	Below 25	Number of Workers	183	49	0	232
		Average dose (mSv)	0.49	0.27	0.00	0.44
		% tritium	14.0	4.5	0.0	12.8
	25-34	Number of Workers	1717	414	0	2131
		Average dose (mSv)	1.22	0.27	0.00	1.03
		% tritium	23.1	24.7	0.0	23.1
	35-44	Number of Workers	4676	759	0	5435
		Average dose (mSv)	1.12	0.26	0.00	1.00
		% tritium	19.4	16.4	0.0	19.3
	45-54	Number of Workers	4358	397	0	4755
		Average dose (mSv)	0.79	0.11	0.00	0.73
		% tritium	16.8	23.8	0.0	16.9
	55-up	Number of Workers	1009	31	0	1040
		Average dose (mSv)	0.54	0.39	.00	0.54
		% tritium	17.2	9.5	0.0	17.0
	Unknown	Number of Workers	245	11	0	256
		Average dose (mSv)	0.55	0.38	0.00	0.54
		% tritium	20.7	34.9	0.0	21.1
	Overall	**Number of Workers**	**12188**	**1661**	**0**	**13849**
		Average dose (mSv)	**0.95**	**0.23**	**0.00**	**0.86**
		% tritium	**19.1**	**19.2**	**0.0**	**19.1**
Mining	Below 25	Number of Workers	174	37	2	213
		Average dose (mSv)	0.87	0.40	0.05	0.78
		% radon progeny	63.6	74.8	100.0	64.6
	25-34	Number of Workers	595	82	8	685
		Average dose (mSv)	1.10	0.22	0.07	0.98
		% radon progeny	77.8	86.8	45.5	78.0
	35-44	Number of Workers	751	71	5	827
		Average dose (mSv)	1.04	0.36	0.11	0.98
		% radon progeny	71.9	88.6	100.0	72.4
	45-54	Number of Workers	492	23	9	524
		Average dose (mSv)	0.90	0.11	0.17	0.85
		% radon progeny	80.1	100.0	100.0	80.3
	55-up	Number of Workers	172	6	3	181
		Average dose (mSv)	0.51	0.12	0.00	0.49
		% radon progeny	82.4	100.0	0.0	82.5
	Unknown	Number of Workers	27	1	0	28
		Average dose (mSv)	0.98	0.00	0.00	0.94
		% radon progeny	79.2	0.0	0.0	79.2
	Overall	**Number of Workers**	**2211**	**220**	**27**	**2458**
		Average dose (mSv)	**0.97**	**0.28**	**0.10**	**0.90**
		% radon progeny	**75.3**	**85.4**	**89.1**	**75.6**

Table 4
Dose Statistics by job category
Administrator

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	348	0.00	0.00
>0-1	176	61.12	0.35
>1-2	1	1.74	1.74
>2-5	0	0.00	0.00
>5-20	0	0.00	0.00
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	525	62.86	0.12
			Five year period 1994-1998
0	469	0.00	0.00
>0-5	392	377.88	0.96
>5-25	1	8.60	8.60
>25-100	0	0.00	0.00
>100	0	0.00	0.00
Total	862	386.48	0.45

Hybrid lognormal parameters for positive doses in 1998:
ρ: 11.6257
μ: 5.3202
σ^2: 9.0661
Sample size: 177
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

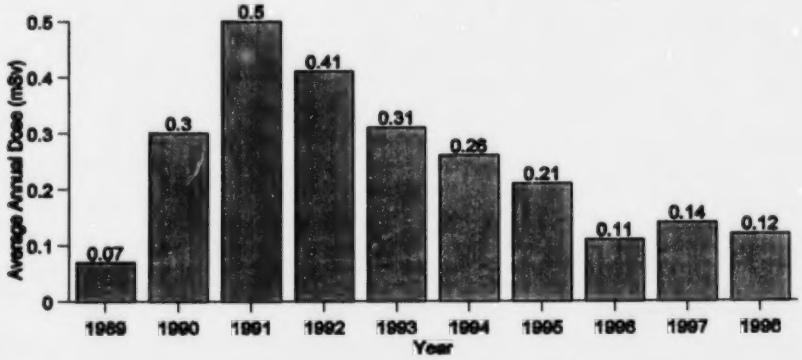


Table 4 (Cont'd)
Office Staff

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	3038	0.00	0.00
>0-1	439	140.27	0.32
>1-2	11	14.67	1.33
>2-5	6	17.26	2.88
>5-20	0	0.00	0.00
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	3494	172.20	0.05
			Five year period 1994-1998
0	5094	0.00	0.00
>0-5	1424	1375.65	0.97
>5-25	17	140.13	8.24
>25-100	1	35.00	35.00
>100	0	0.00	0.00
Total	6536	1550.78	0.24

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.2903
μ: -2.4282
σ^2: 0.9112
Sample size: 456
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

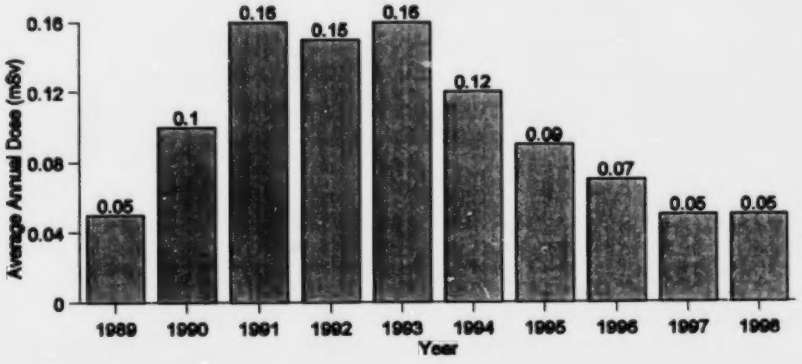


Table 4 (Cont'd)
Safety Officer

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	69	0.00	0.00
>0-1	22	7.96	0.36
>1-2	4	6.70	1.68
>2-5	1	2.60	2.60
>5-20	0	0.00	0.00
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	96	17.26	0.18
			Five year period 1994-1998
0	96	0.00	0.00
>0-5	67	63.03	0.94
>5-25	1	16.30	16.30
>25-100	0	0.00	0.00
>100	0	0.00	0.00
Total	164	79.33	0.48

Lognormal parameters for positive doses in 1998:
μ: -0.8849
σ^2: 0.9768
Sample size: 27
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

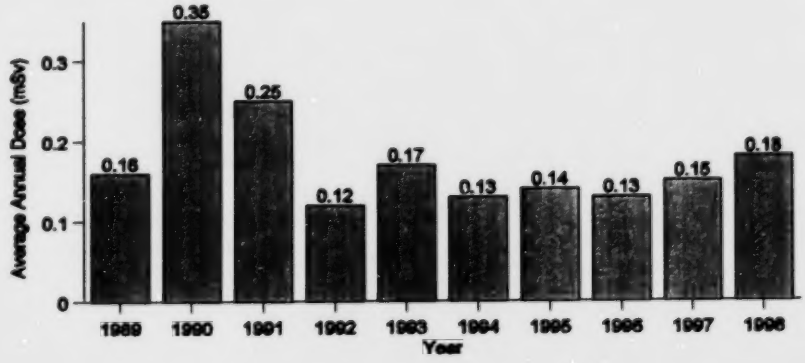


Table 4 (Cont'd)
Industrial Radiographer

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	1113	0.00	0.00
>0-1	372	178.45	0.48
>1-2	184	275.96	1.50
>2-5	309	1053.67	3.41
>5-20	402	4086.29	10.16
>20-50	47	1291.26	27.47
>50	2	143.90	71.95
Total	2429	7029.53	2.89
			Five year period 1994-1998
0	1299	0.00	0.00
>0-5	1110	1589.27	1.43
>5-25	734	9835.72	13.40
>25-100	473	21922.85	46.35
>100	37	4966.09	134.22
Total	3653	38313.93	10.49

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.0419
μ: -2.0553
σ^2: 2.6046
Sample size: 1316
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

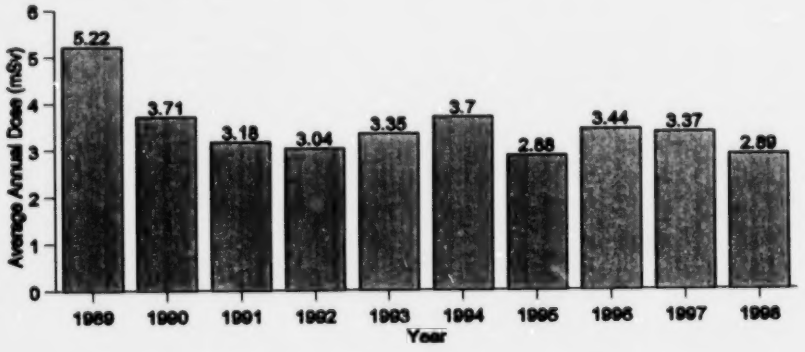


Table 4 (Cont'd)
Instructor (Non Medical)

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	148	0.00	0.00
>0-1	20	5.90	0.30
>1-2	0	0.00	0.00
>2-5	0	0.00	0.00
>5-20	0	0.00	0.00
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	168	5.90	0.04
			Five year period 1994-1998
0	207	0.00	0.00
>0-5	76	50.30	0.66
>5-25	0	0.00	0.00
>25-100	0	0.00	0.00
>100	0	0.00	0.00
Total	283	50.30	0.18

Lognormal parameters for positive doses in 1998:
μ: -1.3905
σ^2: 0.3207
Sample size: 20
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

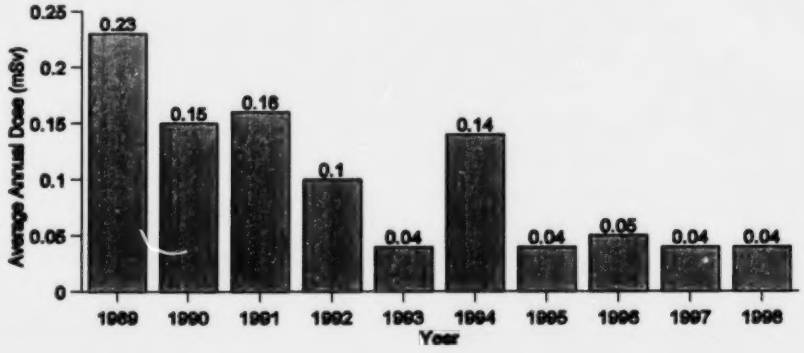


Table 4 (Cont'd)
Instrument Technician

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	1321	0.00	0.00
>0-1	375	139.04	0.37
>1-2	31	44.30	1.43
>2-5	27	83.58	3.10
>5-20	30	259.33	8.64
>20-50	2	52.20	26.10
>50	0	0.00	0.00
Total	1786	578.45	0.32
			Five year period 1994-1998
0	1670	0.00	0.00
>0-5	1051	1032.91	0.98
>5-25	109	1074.65	9.86
>25-100	11	406.23	36.93
>100	0	0.00	0.00
Total	2841	2513.79	0.88

Lognormal parameters for positive doses in 1998:
μ: -0.7149
σ^2: 1.4277
Sample size: 465
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

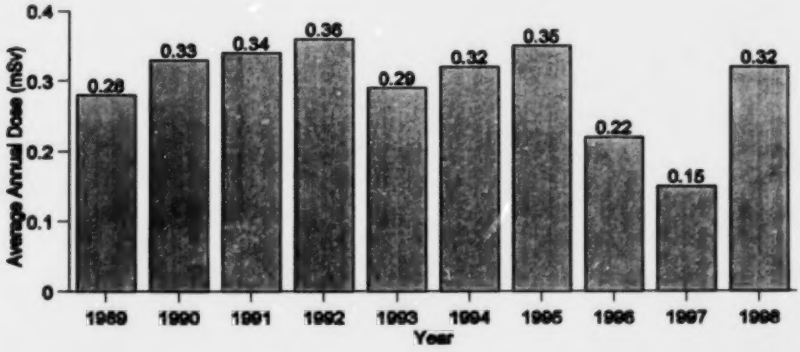


Table 4 (Cont'd)
Laboratory Technician (Industrial)

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	2860	0.00	0.00
>0-1	841	275.69	0.33
>1-2	55	79.33	1.44
>2-5	37	110.36	2.98
>5-20	16	117.81	7.36
>20-50	1	21.40	21.40
>50	0	0.00	0.00
Total	3810	604.59	0.16
			Five year period 1994-1998
0	4493	0.00	0.00
>0-5	2315	1779.08	0.77
>5-25	130	1335.05	10.27
>25-100	6	205.17	34.20
>100	1	550.00	550.00
Total	6945	3869.30	0.56

Lognormal parameters for positive doses in 1998:
μ: -1.1140
σ^2: 1.1161
Sample size: 950
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

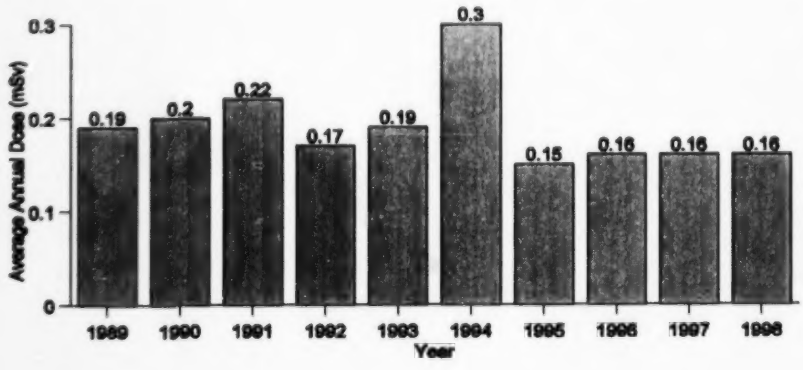


Table 4 (Cont'd)
Nuclear Fuel Processor

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	53	0.00	0.00
>0-1	41	21.30	0.52
>1-2	24	34.40	1.43
>2-5	32	110.90	3.47
>5-20	23	186.00	8.09
>20-50	0	0.00	0.00
>50	1	354.00	354.00
Total	174	706.60	4.06
			Five year period 1994-1998
0	31	0.00	0.00
>0-5	89	203.90	2.29
>5-25	79	1006.10	12.74
>25-100	27	1009.20	37.38
>100	1	371.40	371.40
Total	227	2590.60	11.41

Lognormal parameters for positive doses in 1998:
μ: 0.5721
σ^2: 1.4737
Sample size: 121
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

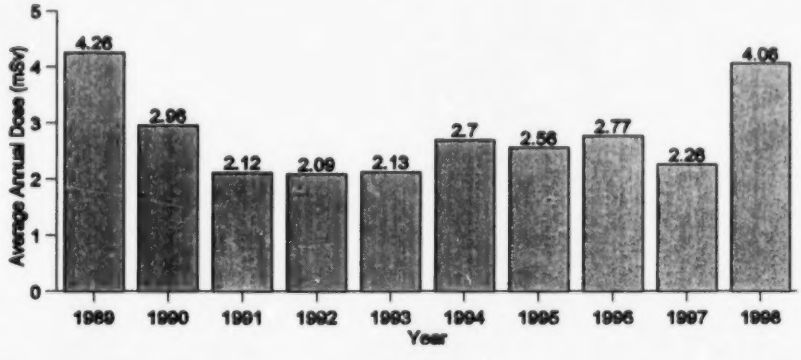


Table 4 (Cont'd)
Scientist/Engineer (Field)

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	665	0.00	0.00
>0-1	603	226.10	0.37
>1-2	32	43.64	1.36
>2-5	14	44.56	3.18
>5-20	7	70.89	10.13
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	1321	385.19	0.29
			Five year period 1994-1998
0	830	0.00	0.00
>0-5	1394	1622.74	1.16
>5-25	78	847.15	10.86
>25-100	6	199.44	33.24
>100	0	0.00	0.00
Total	2308	2669.33	1.16

Lognormal parameters for positive doses in 1998:
μ: -1.1161
σ^2: 1.1794
Sample size: 656
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

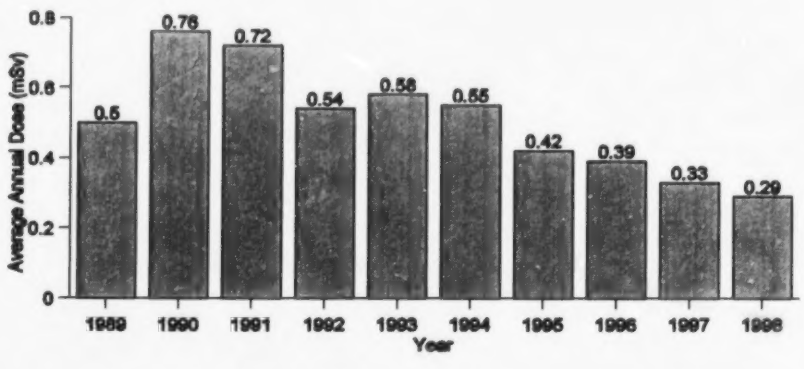


Table 4 (Cont'd)
Scientist/Engineer (Laboratory)

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	4146	0.00	0.00
>0-1	545	163.31	0.30
>1-2	17	23.30	1.37
>2-5	9	27.00	3.00
>5-20	1	7.30	7.30
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	4718	220.91	0.05
			Five year period 1994-1998
0	5850	0.00	0.00
>0-5	2361	1317.28	0.56
>5-25	17	130.77	7.69
>25-100	4	121.00	30.25
>100	0	0.00	0.00
Total	8232	1569.05	0.19

Lognormal parameters for positive doses in 1998:
μ: -1.2729
σ^2: 0.5026
Sample size: 572
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

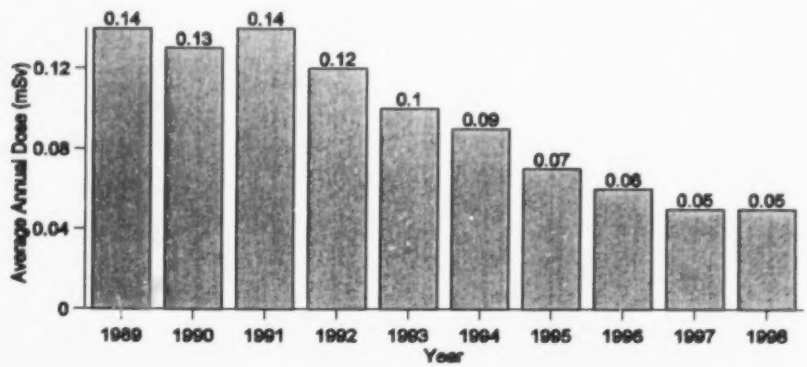


Table 4 (Cont'd)
Well Logger

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	515	0.00	0.00
>0-1	232	101.10	0.44
>1-2	65	98.50	1.52
>2-5	36	117.20	3.26
>5-20	7	55.70	7.96
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	855	372.50	0.44
			Five year period 1994-1998
0	559	0.00	0.00
>0-5	914	1237.27	1.35
>5-25	152	1442.00	9.49
>25-100	4	138.00	34.50
>100	0	0.00	0.00
Total	1629	2817.27	1.73

Lognormal parameters for positive doses in 1998:
μ: -0.4244
σ^2: 0.9312
Sample size: 340
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

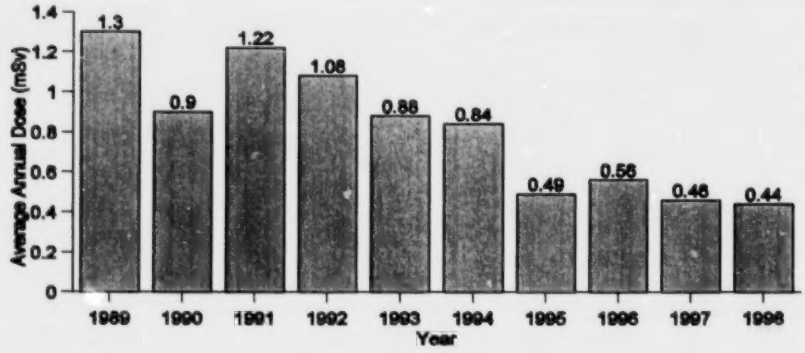


Table 4 (Cont'd)
Chiropractor

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	875	0.00	0.00
>0-1	68	24.60	0.36
>1-2	3	4.70	1.57
>2-5	0	0.00	0.00
>5-20	0	0.00	0.00
>20-50	1	25.60	25.60
>50	0	0.00	0.00
Total	947	54.90	0.06
			Five year period 1994-1998
0	1082	0.00	0.00
>0-5	237	137.40	0.58
>5-25	6	62.80	10.47
>25-100	1	25.60	25.60
>100	0	0.00	0.00
Total	1326	225.80	0.17

Lognormal parameters for positive doses in 1998:
μ: -1.0303
σ^2: 0.5973
Sample size: 72
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

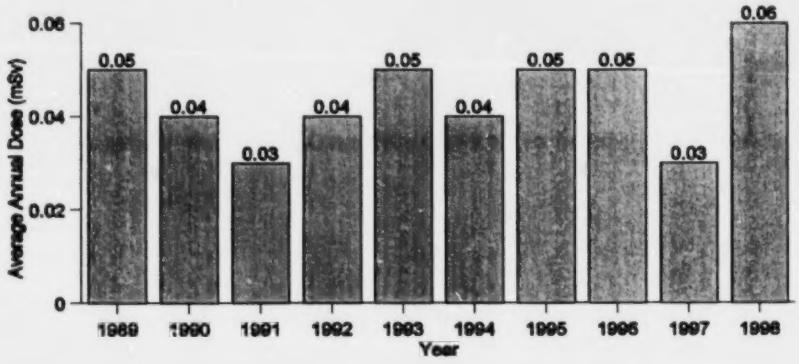


Table 4 (Cont'd)
Dental Assistant

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	8698	0.00	0.00
>0-1	267	76.60	0.29
>1-2	1	1.30	1.30
>2-5	2	4.90	2.45
>5-20	2	11.60	5.80
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	8970	94.40	0.01
			Five year period 1994-1998
0	11415	0.00	0.00
>0-5	545	209.00	0.38
>5-25	13	127.40	9.80
>25-100	0	0.00	0.00
>100	0	0.00	0.00
Total	11973	336.40	0.03

Lognormal parameters for positive doses in 1998:
μ: -1.2799
σ^2: 0.2450
Sample size: 272
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

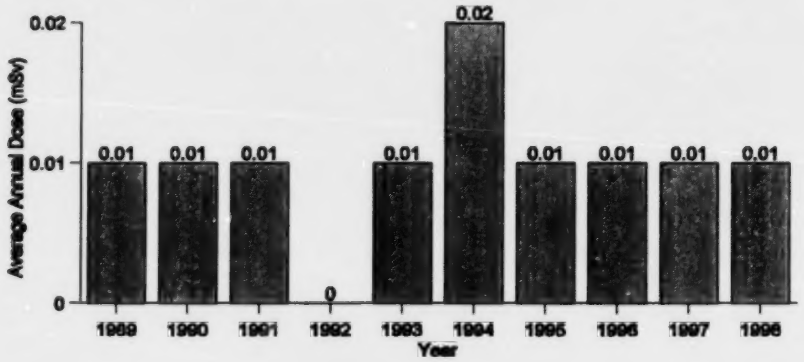


Table 4 (Cont'd)
Dental Hygienist

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	6649	0.00	0.00
>0-1	200	59.00	0.30
>1-2	6	9.20	1.53
>2-5	1	3.80	3.80
>5-20	1	19.00	19.00
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	6857	91.00	0.01
			Five year period 1994-1998
0	9950	0.00	0.00
>0-5	499	215.52	0.43
>5-25	5	60.00	12.00
>25-100	0	0.00	0.00
>100	0	0.00	0.00
Total	10454	275.52	0.03

Lognormal parameters for positive doses in 1998:
μ: -1.2294
σ^2: 0.3479
Sample size: 208
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

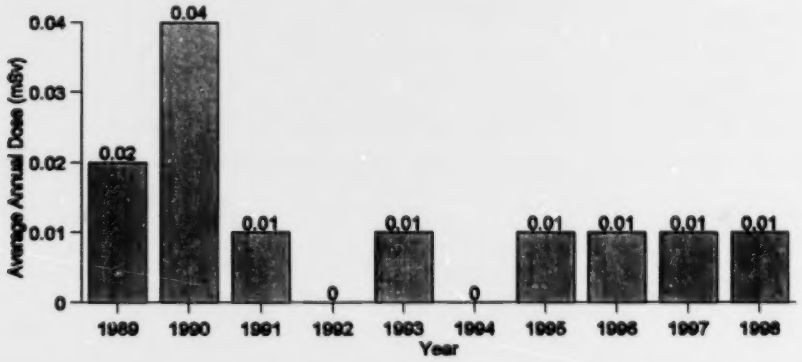


Table 4 (Cont'd)
Dental Therapist/Nurse

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	93	0.00	0.00
>0-1	3	0.90	0.30
>1-2	0	0.00	0.00
>2-5	0	0.00	0.00
>5-20	0	0.00	0.00
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	96	0.90	0.01
			Five year period 1994-1998
0	105	0.00	0.00
>0-5	8	4.10	0.51
>5-25	0	0.00	0.00
>25-100	0	0.00	0.00
>100	0	0.00	0.00
Total	113	4.10	0.04

Lognormal parameters for positive doses in 1998:
μ: -1.2432
σ^2: 0.0808
Sample size: 3
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

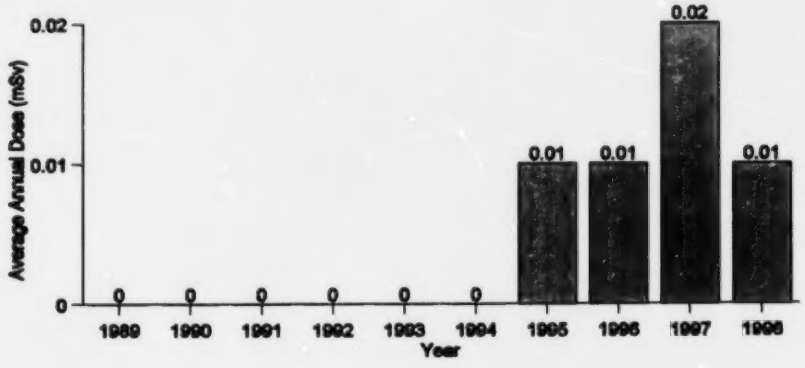


Table 4 (Cont'd)
Dentist

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	6550	0.00	0.00
>0-1	254	74.90	0.29
>1-2	2	2.90	1.45
>2-5	0	0.00	0.00
>5-20	1	6.30	6.30
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	6807	84.10	0.01
			Five year period 1994-1998
0	7932	0.00	0.00
>0-5	632	260.46	0.41
>5-25	7	65.30	9.33
>25-100	0	0.00	0.00
>100	0	0.00	0.00
Total	8571	325.76	0.04

Lognormal parameters for positive doses in 1998:
μ: -1.2943
σ^2: 0.2259
Sample size: 257
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

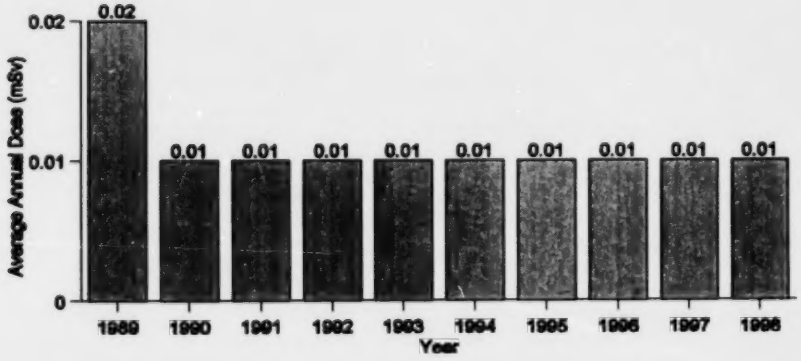


Table 4 (Cont'd)
Gynaecologist

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	23	0.00	0.00
>0-1	2	0.90	0.45
>1-2	2	2.20	1.10
>2-5	0	0.00	0.00
>5-20	0	0.00	0.00
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	27	3.10	0.11
			Five year period 1994-1998
0	40	0.00	0.00
>0-5	13	12.20	0.94
>5-25	0	0.00	0.00
>25-100	0	0.00	0.00
>100	0	0.00	0.00
Total	53	12.20	0.23

Lognormal parameters for positive doses in 1998:
μ: -0.3810
σ^2: 0.2870
Sample size: 4
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

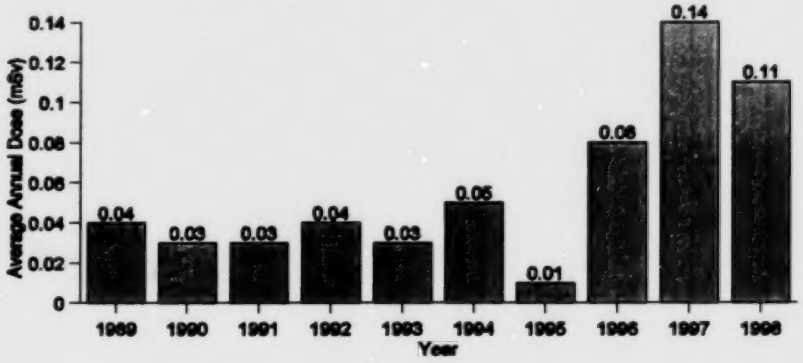


Table 4 (Cont'd)
Laboratory Technician (Medical)

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	2634	0.00	0.00
>0-1	391	125.14	0.32
>1-2	28	39.70	1.42
>2-5	17	55.50	3.26
>5-20	2	13.40	6.70
>20-50	1	33.20	33.20
>50	0	0.00	0.00
Total	3073	266.94	0.09
			Five year period 1994-1998
0	4535	0.00	0.00
>0-5	1567	813.95	0.52
>5-25	26	234.80	9.03
>25-100	3	104.30	34.77
>100	0	0.00	0.00
Total	6131	1153.05	0.19

Lognormal parameters for positive doses in 1998:
μ: -1.1100
σ^2: 0.8313
Sample size: 439
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

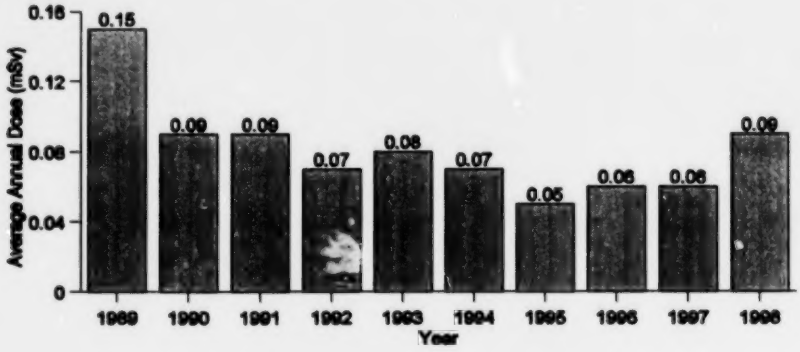


Table 4 (Cont'd)
Medical Physicist

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	219	0.00	0.00
>0-1	53	15.21	0.29
>1-2	3	4.40	1.47
>2-5	1	3.10	3.10
>5-20	0	0.00	0.00
>20-50	1	41.20	41.20
>50	0	0.00	0.00
Total	277	63.91	0.23
			Five year period 1994-1998
0	258	0.00	0.00
>0-5	136	83.71	0.62
>5-25	5	47.90	9.58
>25-100	1	43.70	43.70
>100	0	0.00	0.00
Total	400	175.31	0.44

Lognormal parameters for positive doses in 1998:
μ: -1.1718
σ^2: 0.9465
Sample size: 58
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

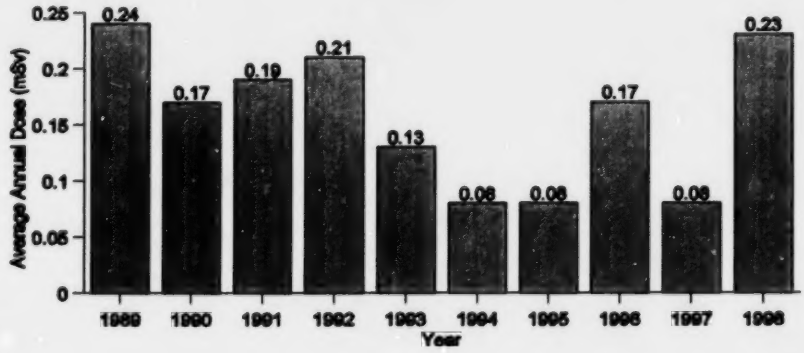


Table 4 (Cont'd)
Medical Radiation Technologist

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	9428	0.00	0.00
>0-1	2104	730.80	0.35
>1-2	97	141.70	1.46
>2-5	55	165.60	3.01
>5-20	5	43.30	8.66
>20-50	1	20.10	20.10
>50	0	0.00	0.00
Total	11690	1101.50	0.09
			Five year period 1994-1998
0	8406	0.00	0.00
>0-5	6222	4060.55	0.65
>5-25	99	859.00	8.68
>25-100	7	260.30	37.19
>100	0	0.00	0.00
Total	14734	5179.85	0.35

Lognormal parameters for positive doses in 1998:
μ: -1.0842
σ^2: 0.5435
Sample size: 2262
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

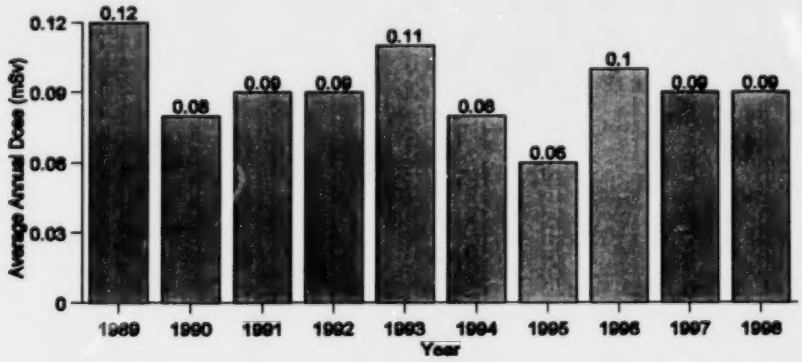


Table 4 (Cont'd)
Nuclear Medicine Technologist

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	381	0.00	0.00
>0-1	334	170.90	0.51
>1-2	311	477.80	1.54
>2-5	370	1145.90	3.10
>5-20	38	273.40	7.19
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	1434	2068.00	1.44
			Five year period 1994-1998
0	470	0.00	0.00
>0-5	821	1599.17	1.95
>5-25	683	7066.40	10.35
>25-100	16	564.50	35.28
>100	0	0.00	0.00
Total	1990	9230.07	4.64

Hybrid lognormal parameters for positive doses in 1998:
p: 0.3012
μ: -0.3008
σ^2: 1.9291
Sample size: 1053
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

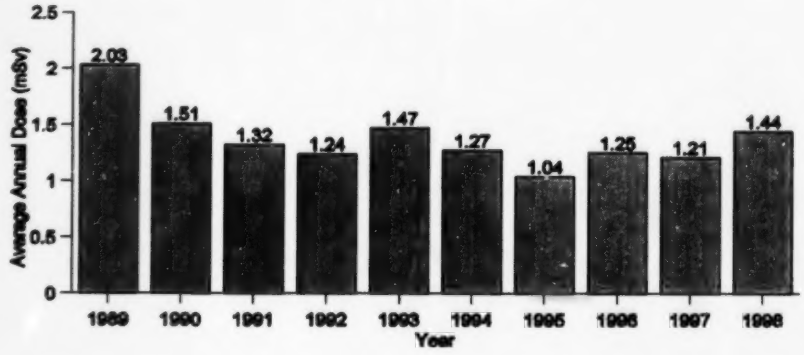


Table 4 (Cont'd)
Nurse

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	3334	0.00	0.00
>0-1	907	440.96	0.49
>1-2	306	386.70	1.26
>2-5	22	65.30	2.97
>5-20	6	39.50	6.58
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	4575	932.46	0.20
			Five year period 1994-1998
0	5515	0.00	0.00
>0-5	2684	2316.75	0.86
>5-25	29	251.20	8.66
>25-100	0	0.00	0.00
>100	0	0.00	0.00
Total	8228	2567.95	0.31

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.1629
μ: -2.2937
σ^2: 0.8446
Sample size: 1241
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

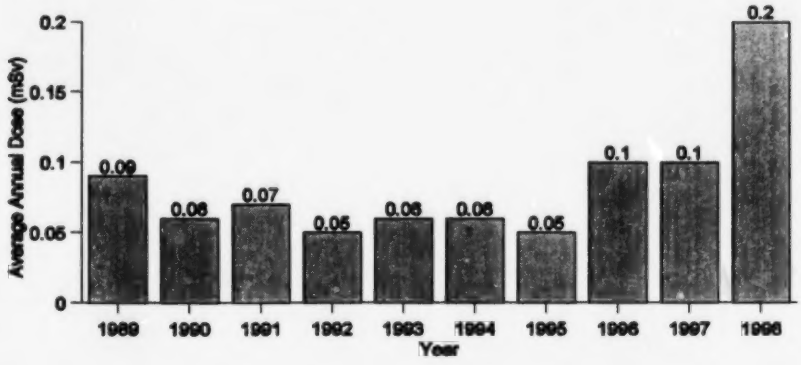


Table 4 (Cont'd)
Physician

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	1461	0.00	0.00
>0-1	449	180.20	0.40
>1-2	47	66.40	1.41
>2-5	20	62.20	3.11
>5-20	8	83.50	10.44
>20-50	2	81.00	40.50
>50	0	0.00	0.00
Total	1987	473.30	0.24
			Five year period 1994-1998
0	1666	0.00	0.00
>0-5	1243	1085.20	0.87
>5-25	58	531.10	9.16
>25-100	7	261.50	37.36
>100	0	0.00	0.00
Total	2974	1877.80	0.63

Lognormal parameters for positive doses in 1998:
μ: -0.8313
σ^2: 0.9304
Sample size: 526
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

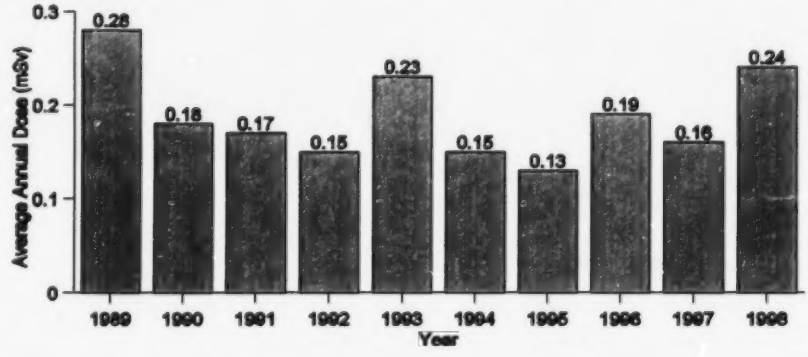


Table 4 (Cont'd)
Radiation Therapist

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	755	0.00	0.00
>0-1	264	77.50	0.29
>1-2	8	11.40	1.43
>2-5	6	19.70	3.28
>5-20	2	13.40	6.70
>20-50	1	24.00	24.00
>50	0	0.00	0.00
Total	1036	146.00	0.14
			Five year period 1994-1998
0	508	0.00	0.00
>0-5	813	690.50	0.85
>5-25	24	266.20	11.09
>25-100	3	136.10	45.37
>100	0	0.00	0.00
Total	1348	1092.80	0.81

Lognormal parameters for positive doses in 1998:
μ: -1.2550
σ^2: 0.6824
Sample size: 281
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

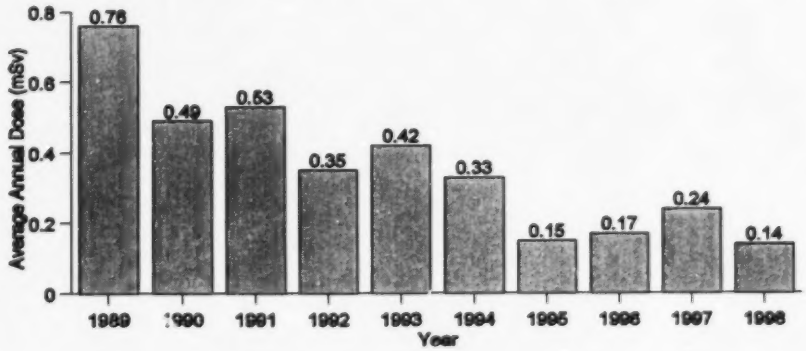


Table 4 (Cont'd)
Radiologist (Diagnostic)

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	1320	0.00	0.00
>0-1	390	142.50	0.37
>1-2	35	46.20	1.32
>2-5	18	48.30	2.68
>5-20	3	23.70	7.90
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	1766	260.70	0.15
			Five year period 1994-1998
0	1251	0.00	0.00
>0-5	1061	841.50	0.79
>5-25	41	379.30	9.25
>25-100	1	32.10	32.10
>100	0	0.00	0.00
Total	2354	1252.90	0.53

Lognormal parameters for positive doses in 1998:
μ: -0.9701
σ^2: 0.7145
Sample size: 446
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

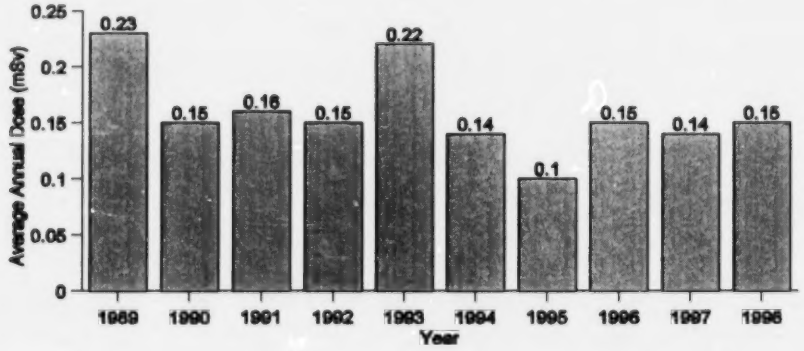


Table 4 (Cont'd)
Radiologist (Therapeutic)

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	124	0.00	0.00
>0-1	22	6.90	0.31
>1-2	1	1.10	1.10
>2-5	1	2.20	2.20
>5-20	1	8.70	8.70
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	149	18.90	0.13
			Five year period 1994-1998
0	153	0.00	0.00
>0-5	107	66.80	0.62
>5-25	2	30.30	15.15
>25-100	0	0.00	0.00
>100	0	0.00	0.00
Total	262	97.10	0.37

Lognormal parameters for positive doses in 1998:
μ: -1.0401
σ^2: 0.9151
Sample size: 25
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

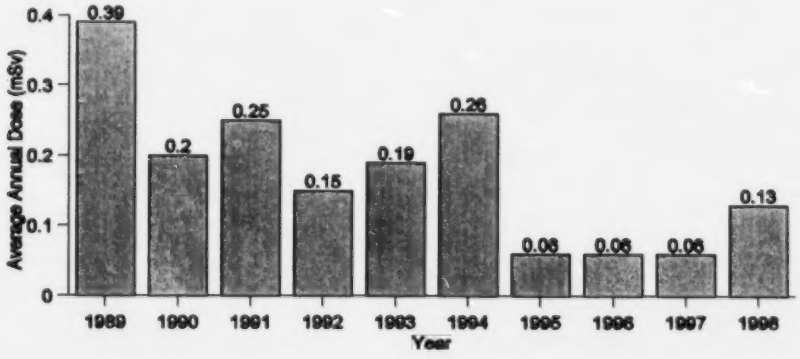


Table 4 (Cont'd)
Veterinarian

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	3752	0.00	0.00
>0-1	391	122.61	0.31
>1-2	19	27.90	1.47
>2-5	7	20.40	2.91
>5-20	1	5.90	5.90
>20-50	2	56.60	28.30
>50	0	0.00	0.00
Total	4172	233.41	0.06
			Five year period 1994-1998
0	4346	0.00	0.00
>0-5	1347	713.47	0.53
>5-25	21	158.00	7.52
>25-100	2	60.60	30.30
>100	0	0.00	0.00
Total	5716	932.07	0.16

Lognormal parameters for positive doses in 1998:
μ: -1.1100
σ^2: 0.4599
Sample size: 420
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

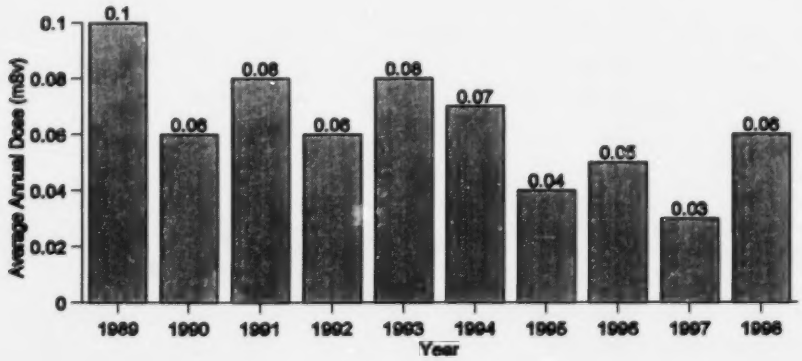


Table 4 (Cont'd)
Veterinary Technician

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	160	0.00	0.00
>0-1	9	2.50	0.28
>1-2	1	1.20	1.20
>2-5	0	0.00	0.00
>5-20	0	0.00	0.00
>20-50	0	0.00	0.00
>50	0	0.00	0.00
Total	170	3.70	0.02
			Five year period 1994-1998
0	187	0.00	0.00
>0-5	19	13.80	0.73
>5-25	1	6.20	6.20
>25-100	0	0.00	0.00
>100	0	0.00	0.00
Total	207	20.00	0.10

Lognormal parameters for positive doses in 1998:
μ: -1.1818
σ^2: 0.2987
Sample size: 10
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

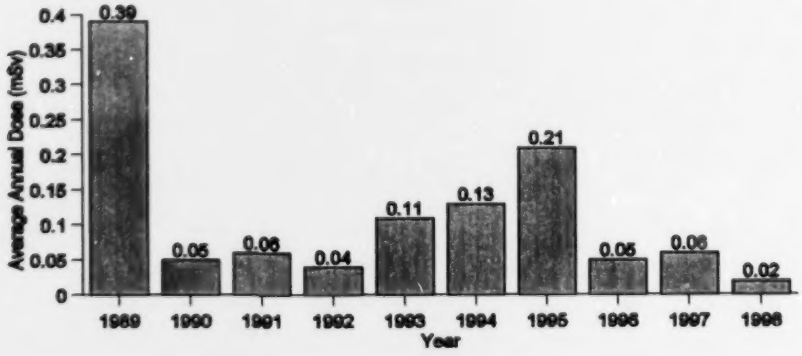


Table 4 (Cont'd)
Ward Aid/Orderly

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose
			Year 1998
0	1322	0.00	0.00
>0-1	192	78.50	0.41
>1-2	15	20.10	1.34
>2-5	10	29.40	2.94
>5-20	1	6.90	6.90
>20-50	0	0.00	0.00
>50	1	63.40	63.40
Total	1541	198.30	0.13
			Five year period 1994-1998
0	2471	0.00	0.00
>0-5	672	463.20	0.69
>5-25	17	143.40	8.44
>25-100	2	95.40	47.70
>100	0	0.00	0.00
Total	3162	702.00	0.22

Lognormal parameters for positive doses in 1998:
μ: -0.8466
σ^2: 0.7618
Sample size: 219
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

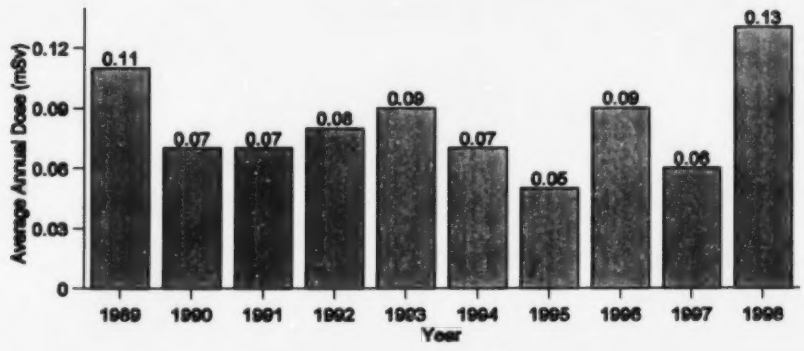


Table 4 (Cont'd)
Reactor-Administration

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Tritium
				Year 1998
0	3909	0.00	0.00	0
>0-1	859	244.50	0.28	42
>1-2	149	214.34	1.44	35
>2-5	131	396.46	3.03	34
>5-20	27	189.63	7.02	19
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	5075	1044.93	0.21	33
				Five year period 1994-1998
0	4602	0.00	0.00	0
>0-5	2276	2250.98	0.99	34
>5-25	259	2465.41	9.52	25
>25-100	3	99.78	33.26	11
>100	0	0.00	0.00	0
Total	7140	4816.17	0.67	29

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.1255
μ: -3.0434
σ^2: 2.6564
Sample size: 1166
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

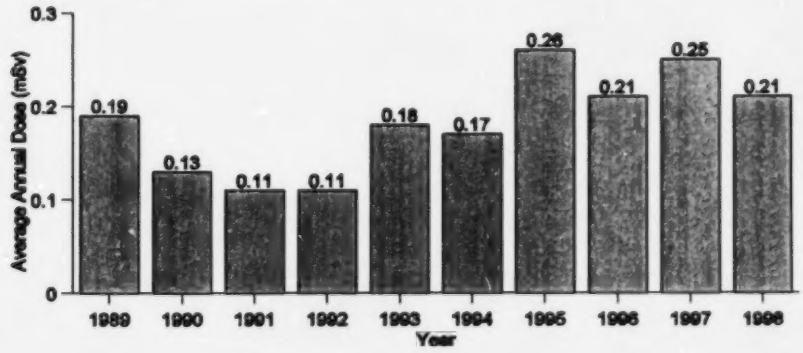


Table 4 (Cont'd)
Reactor-Chemical and Radiation Control

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Tritium
				Year 1998
0	122	0.00	0.00	0
>0-1	146	52.89	0.36	57
>1-2	41	59.60	1.45	32
>2-5	24	81.93	3.41	9
>5-20	32	320.30	10.01	10
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	365	514.72	1.41	17
				Five year period 1994-1998
0	166	0.00	0.00	0
>0-5	234	320.30	1.37	49
>5-25	113	1244.62	11.01	26
>25-100	44	2026.30	46.05	8
>100	0	0.00	0.00	0
Total	557	3591.22	6.45	18

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.0518
μ: -3.2620
σ^2: 3.1908
Sample size: 243
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

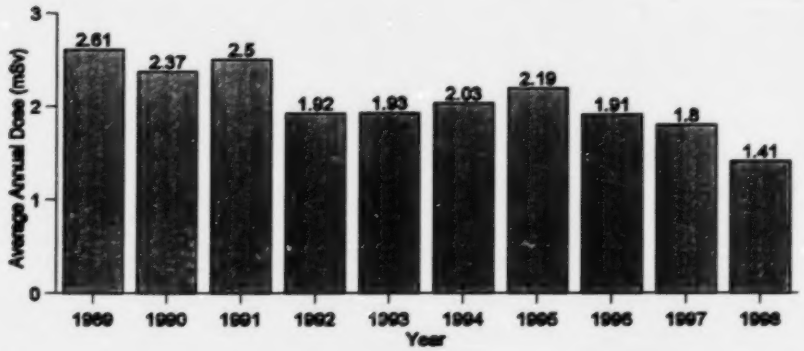


Table 4 (Cont'd)
Reactor-Construction

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Tritium
				Year 1998
0	502	0.00	0.00	0
>0-1	250	79.44	0.32	32
>1-2	103	154.13	1.50	24
>2-5	179	612.34	3.42	18
>5-20	114	990.41	8.69	11
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	1148	1836.32	1.60	15
				Five year period 1994-1998
0	1019	0.00	0.00	0
>0-5	823	1199.51	1.46	17
>5-25	548	6727.34	12.28	11
>25-100	172	6520.48	37.91	10
>100	0	0.00	0.00	0
Total	2562	14447.33	5.64	11

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.2533
μ: -0.5433
σ^2: 5.7968
Sample size: 646
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

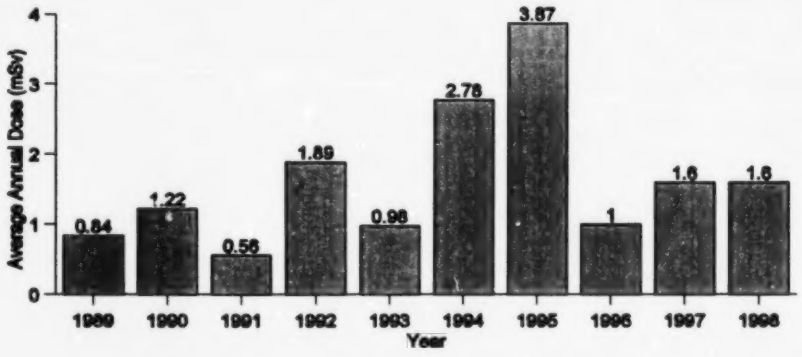


Table 4 (Cont'd)
Reactor-Control Technician

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Tritium
				Year 1998
0	54	0.00	0.00	0
>0-1	24	11.83	0.49	20
>1-2	11	15.34	1.39	25
>2-5	15	51.98	3.47	15
>5-20	13	95.13	7.32	8
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	117	174.28	1.49	13
				Five year period 1994-1998
0	76	0.00	0.00	0
>0-5	49	69.31	1.41	28
>5-25	39	414.41	10.63	25
>25-100	8	233.56	29.20	11
>100	0	0.00	0.00	0
Total	172	717.28	4.17	21

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.1163
μ: -1.4268
σ^2: 2.3194
Sample size: 63
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

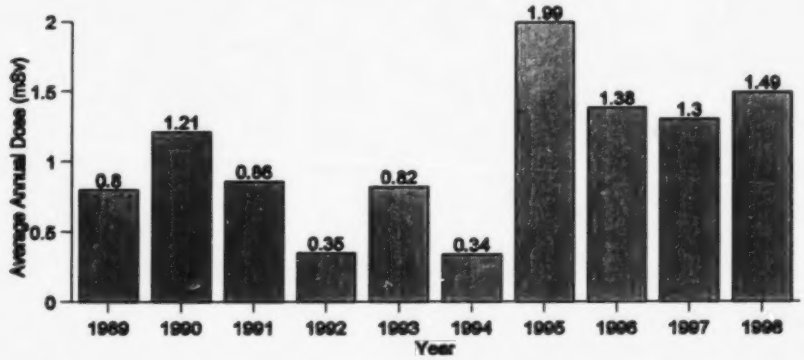


Table 4 (Cont'd)
Reactor-Electrical Maintenance

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Tritium
				Year 1998
0	389	0.00	0.00	0
>0-1	320	119.47	0.37	28
>1-2	125	176.63	1.41	23
>2-5	77	254.39	3.30	17
>5-20	44	354.01	8.05	8
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	955	904.50	0.95	16
				Five year period 1994-1998
0	302	0.00	0.00	0
>0-5	647	1000.42	1.55	26
>5-25	430	4801.97	11.17	24
>25-100	28	818.94	29.25	17
>100	0	0.00	0.00	0
Total	1407	6621.33	4.71	24

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.1610
μ: -2.0307
σ^2: 3.4722
Sample size: 566
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

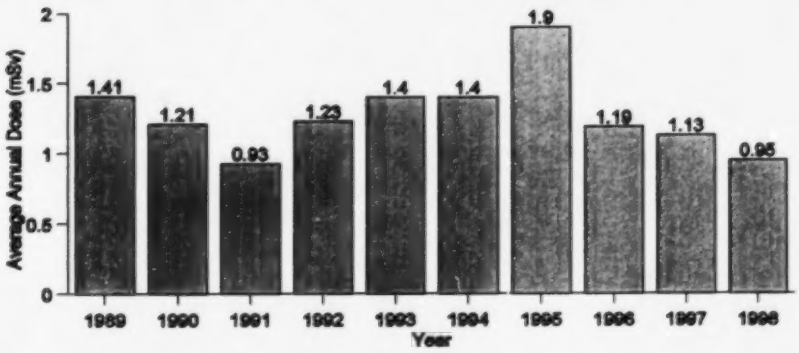


Table 4 (Cont'd)
Reactor-Fuel Handling

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Tritium
				Year 1998
0	3	0.00	0.00	0
>0-1	7	3.11	0.44	11
>1-2	3	4.19	1.40	12
>2-5	14	53.10	3.79	12
>5-20	28	199.93	7.14	14
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	55	260.33	4.73	14
				Five year period 1994-1998
0	12	0.00	0.00	0
>0-5	58	114.29	1.97	16
>5-25	83	1240.31	14.94	14
>25-100	41	1369.11	33.39	21
>100	0	0.00	0.00	0
Total	194	2723.71	14.04	17

Hybrid lognormal parameters for positive doses in 1998:
ρ: 1.4525
μ: 8.8993
σ^2: 27.0076
Sample size: 52
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

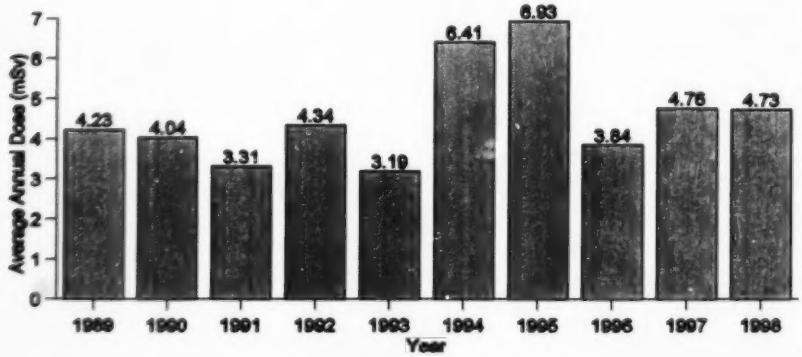


Table 4 (Cont'd)
Reactor-General Maintenance

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Tritium
				Year 1998
0	679	0.00	0.00	0
>0-1	242	81.06	0.33	30
>1-2	58	83.30	1.44	18
>2-5	95	290.67	3.06	14
>5-20	73	574.36	7.87	8
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	1147	1029.39	0.90	12
				Five year period 1994-1998
0	985	0.00	0.00	0
>0-5	765	997.13	1.30	30
>5-25	311	3649.91	11.74	23
>25-100	42	1341.41	31.94	15
>100	0	0.00	0.00	0
Total	2103	5988.45	2.85	22

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.2240
μ: -1.2690
σ^2: 5.0698
Sample size: 468
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

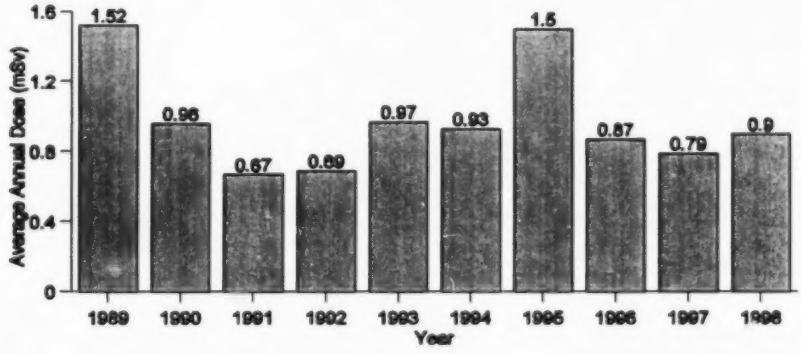


Table 4 (Cont'd)
Reactor-Health Physics

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Tritium
				Year 1998
0	39	0.00	0.00	0
>0-1	12	4.37	0.36	20
>1-2	4	7.08	1.77	13
>2-5	1	2.61	2.61	10
>5-20	2	15.31	7.66	9
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	58	29.37	0.51	12
				Five year period 1994-1998
0	81	0.00	0.00	0
>0-5	48	45.88	0.96	23
>5-25	14	159.10	11.36	25
>25-100	2	55.61	27.81	25
>100	0	0.00	0.00	0
Total	145	260.59	1.80	25

Lognormal parameters for positive doses in 1998:
μ: -0.4952
σ^2: 2.0460
Sample size: 19
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

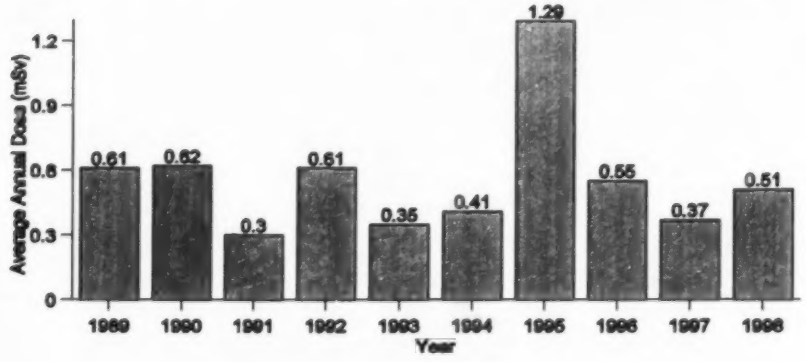


Table 4 (Cont'd)
Reactor-Industrial Radiographer

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Tritium
				Year 1998
0	4	0.00	0.00	0
>0-1	3	1.83	0.61	0
>1-2	0	0.00	0.00	0
>2-5	1	4.56	4.56	16
>5-20	0	0.00	0.00	0
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	8	6.39	0.80	11
				Five year period 1994-1998
0	11	0.00	0.00	0
>0-5	9	14.06	1.56	3
>5-25	13	182.49	14.04	4
>25-100	1	26.39	26.39	6
>100	0	0.00	0.00	0
Total	34	222.94	6.56	4

Lognormal parameters for positive doses in 1998:
μ: -0.2750
σ^2: 1.8502
Sample size: 4
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

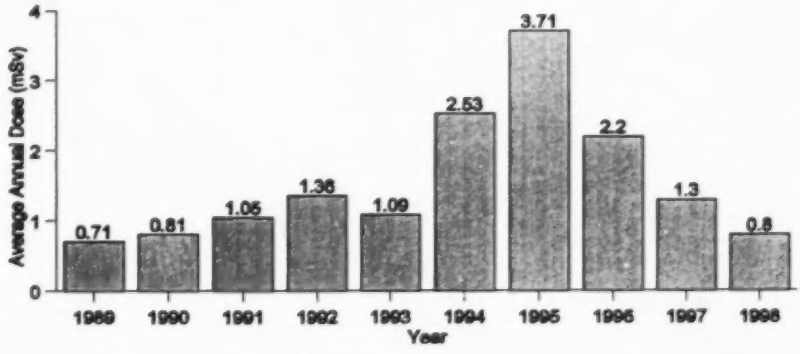


Table 4 (Cont'd)
Reactor-Mechanical Maintenance

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Tritium
				Year 1998
0	393	0.00	0.00	0
>0-1	296	109.61	0.37	34
>1-2	140	203.49	1.45	25
>2-5	208	680.48	3.27	17
>5-20	184	1602.22	8.71	11
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	1221	2595.80	2.13	15
				Five year period 1994-1998
0	455	0.00	0.00	0
>0-5	645	1079.32	1.67	24
>5-25	802	10558.34	13.17	21
>25-100	216	7546.59	34.94	17
>100	0	0.00	0.00	0
Total	2118	19184.25	9.06	19

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.2305
μ: -0.4625
σ^2: 5.3280
Sample size: 828
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

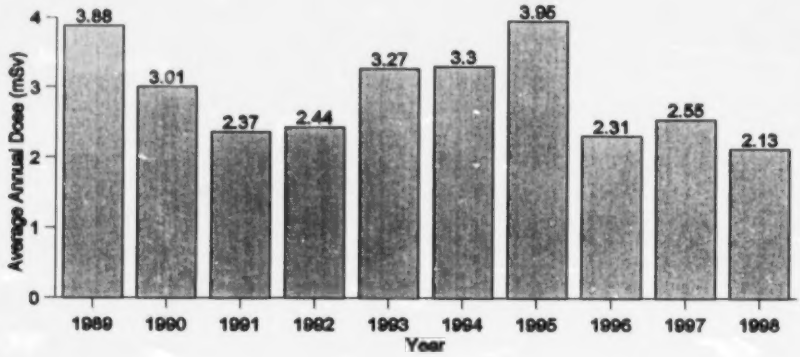


Table 4 (Cont'd)
Reactor-Operations

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Tritium
				Year 1998
0	628	0.00	0.00	0
>0-1	735	274.12	0.37	48
>1-2	257	370.15	1.44	49
>2-5	163	494.62	3.03	43
>5-20	129	1222.53	9.48	15
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	1912	2361.42	1.24	30
				Five year period 1994-1998
0	356	0.00	0.00	0
>0-5	1032	1443.21	1.40	42
>5-25	744	9199.76	12.37	38
>25-100	110	3657.22	33.25	19
>100	0	0.00	0.00	0
Total	2242	14300.19	6.38	34

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.0839
μ: -2.7420
σ^2: 3.1752
Sample size: 1284
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

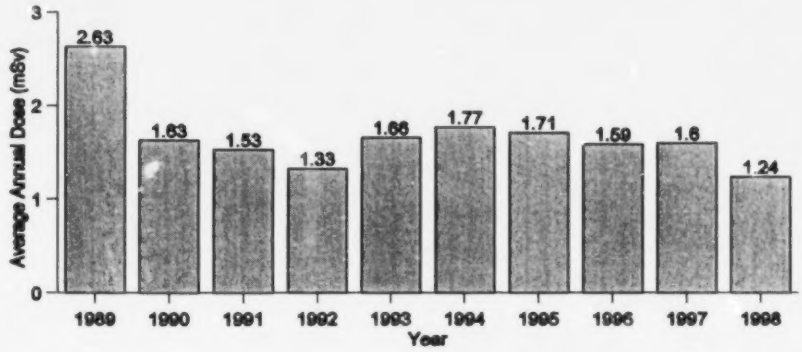


Table 4 (Cont'd)
Reactor-Scientific/Professional

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Tritium
				Year 1998
0	1055	0.00	0.00	0
>0-1	219	74.12	0.34	19
>1-2	53	74.11	1.40	17
>2-5	55	180.97	3.29	13
>5-20	53	433.68	8.18	11
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	1435	762.88	0.53	13
				Five year period 1994-1998
0	1872	0.00	0.00	0
>0-5	701	775.38	1.11	17
>5-25	243	2629.14	10.82	13
>25-100	59	2209.07	37.44	12
>100	0	0.00	0.00	0
Total	2875	5613.59	1.95	13

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.1181
μ: -2.2762
σ^2: 3.7337
Sample size: 380
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

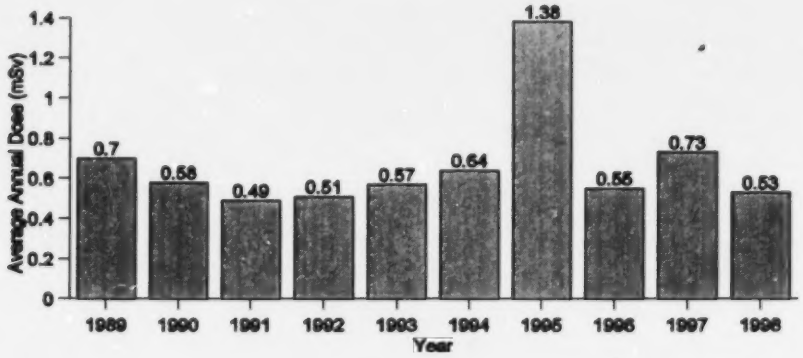


Table 4 (Cont'd)
Reactor-Training

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Tritium
				Year 1998
0	45	0.00	0.00	0
>0-1	9	3.03	0.34	30
>1-2	1	1.10	1.10	34
>2-5	0	0.00	0.00	0
>5-20	3	30.81	10.27	7
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	58	34.94	0.60	10
				Five year period 1994-1998
0	84	0.00	0.00	0
>0-5	32	21.51	0.67	21
>5-25	6	54.81	9.14	17
>25-100	1	38.00	38.00	13
>100	0	0.00	0.00	0
Total	123	114.32	0.93	17

Lognormal parameters for positive doses in 1998:
μ: -0.3590
σ^2: 2.5133
Sample size: 13
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

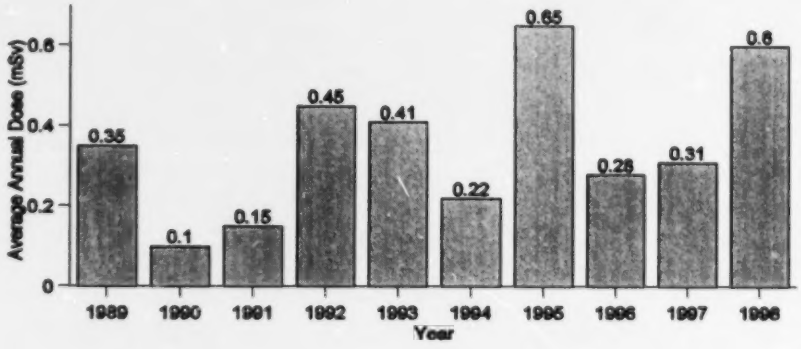


Table 4 (Cont'd)
Reactor-Visitor

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Tritium
				Year 1998
0	541	0.00	0.00	0
>0-1	58	19.82	0.34	23
>1-2	15	21.32	1.42	13
>2-5	27	81.50	3.02	7
>5-20	24	224.19	9.34	11
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	665	346.83	0.52	11
				Five year period 1994-1998
0	658	0.00	0.00	0
>0-5	197	246.12	1.25	7
>5-25	220	2846.91	12.94	3
>25-100	8	270.11	33.76	9
>100	0	0.00	0.00	0
Total	1083	3363.14	3.11	4

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.1814
μ: -1.2355
σ^2: 5.2112
Sample size: 124
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

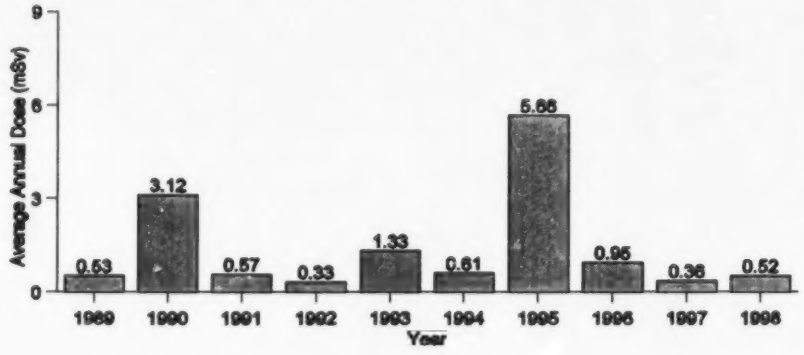


Table 4 (Cont'd)
Uranium Mine Mill Maintenance

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Radon Progeny
				Year 1998
0	9	0.00	0.00	0
>0-1	88	49.40	0.56	97
>1-2	46	61.75	1.34	95
>2-5	15	45.80	3.05	52
>5-20	3	19.30	6.43	23
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	161	176.25	1.09	77
				Five year period 1994-1998
0	34	0.00	0.00	0
>0-5	181	272.05	1.50	62
>5-25	99	1057.00	10.68	44
>25-100	4	108.05	27.01	23
>100	0	0.00	0.00	0
Total	318	1437.10	4.52	45

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.1943
μ: -1.6506
σ^2: 1.2954
Sample size: 152
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

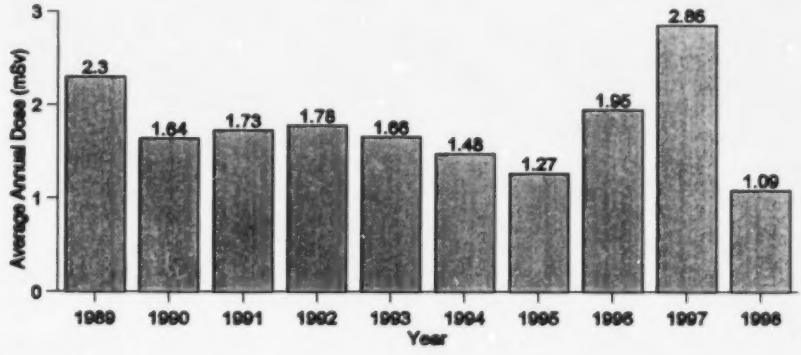


Table 4 (Cont'd)
Uranium Mine Mill Worker

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Radon Progeny
				Year 1998
0	15	0.00	0.00	0
>0-1	79	38.05	0.48	97
>1-2	75	101.90	1.36	92
>2-5	39	124.15	3.18	49
>5-20	4	26.50	6.63	43
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	212	290.60	1.37	70
				Five year period 1994-1998
0	21	0.00	0.00	0
>0-5	201	307.90	1.53	53
>5-25	161	1688.30	10.49	44
>25-100	6	178.45	29.74	25
>100	0	0.00	0.00	0
Total	389	2174.65	5.59	44

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.4317
μ: -0.2411
σ^2: 2.4147
Sample size: 197
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

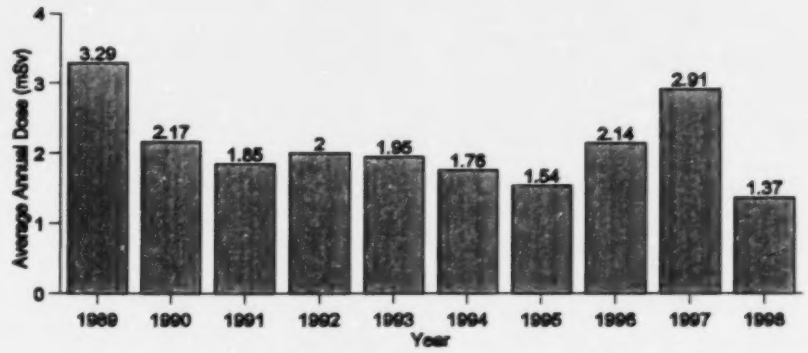


Table 4 (Cont'd)
Uranium Mine Nurse

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Radon Progeny
				Year 1998
0	12	0.00	0.00	0
>0-1	5	0.70	0.14	100
>1-2	0	0.00	0.00	0
>2-5	0	0.00	0.00	0
>5-20	0	0.00	0.00	0
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	17	0.70	0.04	100
				Five year period 1994-1998
0	15	0.00	0.00	0
>0-5	7	3.35	0.48	94
>5-25	0	0.00	0.00	0
>25-100	0	0.00	0.00	0
>100	0	0.00	0.00	0
Total	22	3.35	0.15	94

Lognormal parameters for positive doses in 1998:
μ: -2.3293
σ^2: 0.6975
Sample size: 5
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

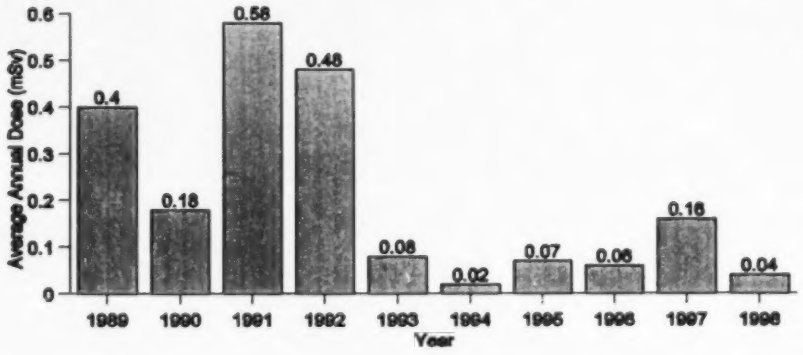


Table 4 (Cont'd)
Uranium Mine Office Staff

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Radon Progeny
				Year 1998
0	82	0.00	0.00	0
>0-1	75	23.15	0.31	91
>1-2	3	4.05	1.35	73
>2-5	0	0.00	0.00	0
>5-20	0	0.00	0.00	0
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	160	27.20	0.17	89
				Five year period 1994-1998
0	118	0.00	0.00	0
>0-5	184	175.00	0.95	75
>5-25	4	28.50	7.13	56
>25-100	0	0.00	0.00	0
>100	0	0.00	0.00	0
Total	306	203.50	0.67	72

Hybrid lognormal parameters for positive doses in 1998:
ρ: 1.0394
μ: -1.0439
σ^2: 1.5132
Sample size: 78
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

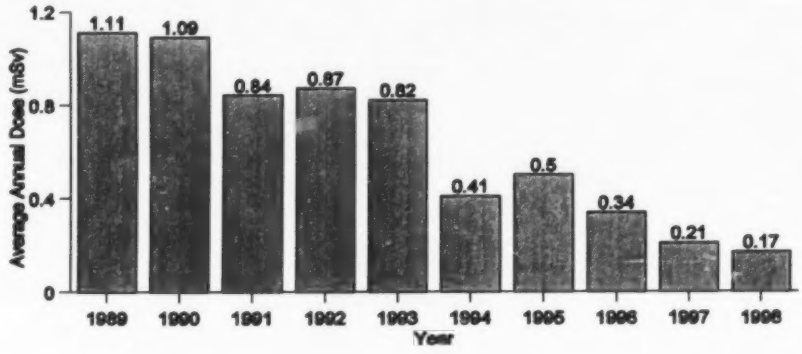


Table 4 (Cont'd)
Uranium Mine Support Worker

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Radon Progeny
				Year 1998
0	34	0.00	0.00	0
>0-1	166	58.75	0.35	97
>1-2	41	58.85	1.44	95
>2-5	31	89.15	2.88	78
>5-20	18	163.30	9.07	54
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	290	370.05	1.28	73
				Five year period 1994-1998
0	45	0.00	0.00	0
>0-5	319	416.27	1.30	73
>5-25	138	1772.70	12.85	56
>25-100	21	642.10	30.58	52
>100	0	0.00	0.00	0
Total	523	2831.07	5.41	58

Lognormal parameters for positive doses in 1998:
μ: -0.5265
σ^2: 1.8034
Sample size: 256
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

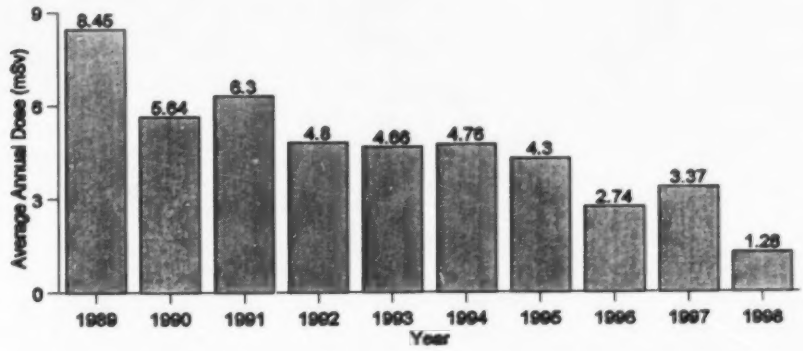


Table 4 (Cont'd)
Uranium Mine Surface Maintenance

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Radon Progeny
				Year 1998
0	68	0.00	0.00	0
>0-1	99	49.25	0.50	96
>1-2	7	9.00	1.29	83
>2-5	2	4.30	2.15	79
>5-20	0	0.00	0.00	0
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	176	62.55	0.36	93
				Five year period 1994-1998
0	114	0.00	0.00	0
>0-5	346	519.60	1.50	66
>5-25	22	179.75	8.17	68
>25-100	1	27.30	27.30	58
>100	0	0.00	0.00	0
Total	483	726.65	1.50	66

Hybrid lognormal parameters for positive doses in 1998:
ρ: 2.7793
μ: 1.7655
σ^2: 3.8953
Sample size: 108
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

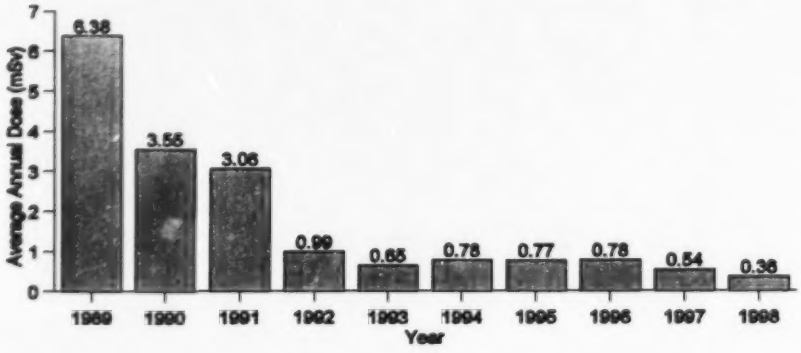


Table 4 (Cont'd)
Uranium Mine Surface Miner

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Radon Progeny
				Year 1998
0	12	0.00	0.00	0
>0-1	61	32.30	0.53	89
>1-2	14	19.00	1.36	35
>2-5	9	25.50	2.83	11
>5-20	0	0.00	0.00	0
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	96	76.80	0.80	50
				Five year period 1994-1998
0	47	0.00	0.00	0
>0-5	243	317.35	1.31	47
>5-25	60	490.95	8.18	31
>25-100	0	0.00	0.00	0
>100	0	0.00	0.00	0
Total	350	808.30	2.31	37

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.5659
μ: -0.5317
σ^2: 1.9109
Sample size: 84
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

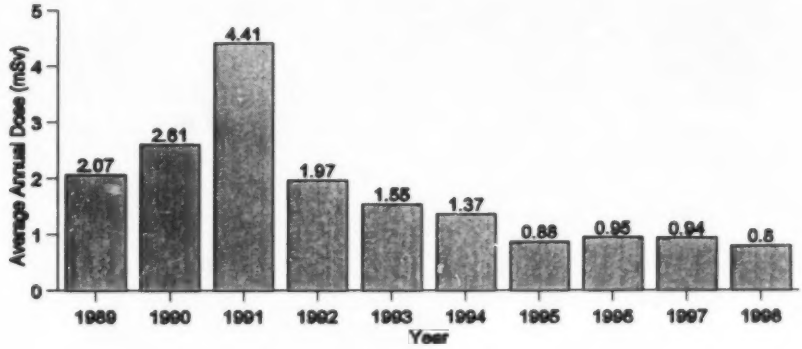


Table 4 (Cont'd)
Uranium Mine Surface Personnel

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Radon Progeny
				Year 1998
0	34	0.00	0.00	0
>0-1	83	28.55	0.34	84
>1-2	5	7.25	1.45	81
>2-5	4	11.00	2.75	63
>5-20	0	0.00	0.00	0
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	126	46.80	0.37	79
				Five year period 1994-1998
0	72	0.00	0.00	0
>0-5	138	128.65	0.93	70
>5-25	4	33.40	8.35	54
>25-100	0	0.00	0.00	0
>100	0	0.00	0.00	0
Total	214	162.05	0.76	66

Lognormal parameters for positive doses in 1998:
μ: -1.1942
σ^2: 1.0682
Sample size: 92
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

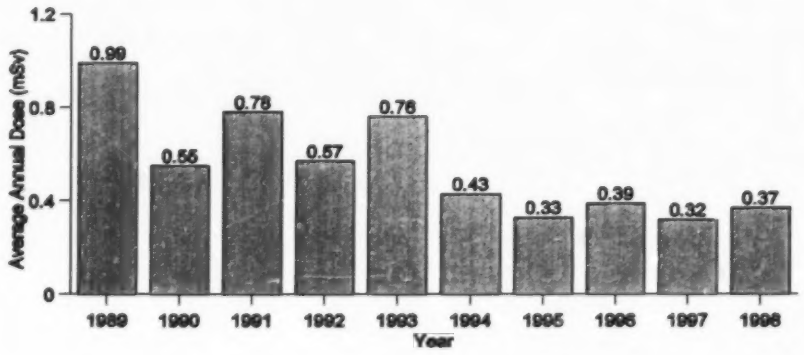


Table 4 (Cont'd)
Uranium Mine Surface Support Worker

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Radon Progeny
				Year 1998
0	125	0.00	0.00	0
>0-1	148	62.75	0.42	87
>1-2	14	20.30	1.45	59
>2-5	5	16.30	3.26	44
>5-20	1	6.95	6.95	67
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	293	106.30	0.36	74
				Five year period 1994-1998
0	285	0.00	0.00	0
>0-5	471	517.25	1.10	54
>5-25	43	348.55	8.11	41
>25-100	0	0.00	0.00	0
>100	0	0.00	0.00	0
Total	799	865.80	1.08	49

Lognormal parameters for positive doses in 1998:
μ: -0.9273
σ^2: 0.9858
Sample size: 168
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

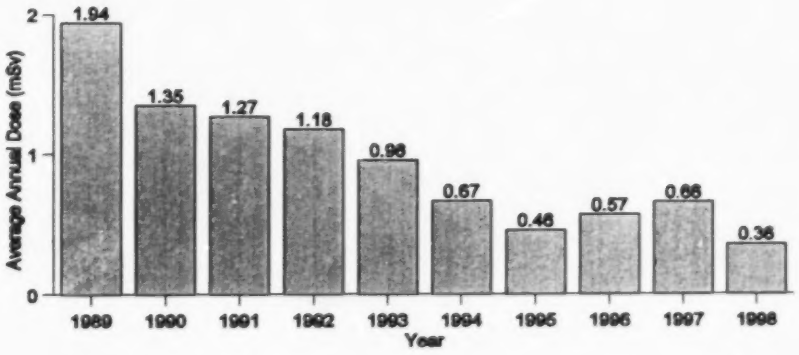


Table 4 (Cont'd)
Uranium Mine Underground Maintenance

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Radon Progeny
				Year 1998
0	22	0.00	0.00	0
>0-1	79	36.60	0.46	96
>1-2	24	33.70	1.40	96
>2-5	9	29.10	3.23	77
>5-20	5	29.75	5.95	75
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	139	129.15	0.93	87
				Five year period 1994-1998
0	23	0.00	0.00	0
>0-5	162	258.35	1.59	70
>5-25	87	939.35	10.80	51
>25-100	6	164.50	27.42	58
>100	0	0.00	0.00	0
Total	278	1362.20	4.90	56

Lognormal parameters for positive doses in 1998:
μ: -0.4892
σ^2: 1.3276
Sample size: 117
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

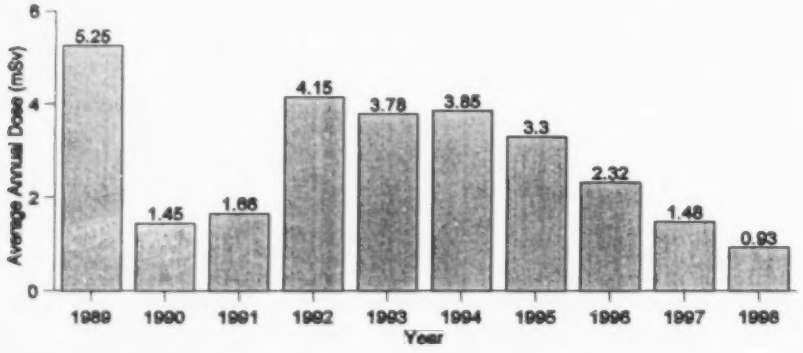


Table 4 (Cont'd)
Uranium Mine Underground Miner

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Radon Progeny
				Year 1998
0	14	0.00	0.00	0
>0-1	147	60.00	0.41	99
>1-2	103	156.40	1.52	99
>2-5	56	168.05	3.00	88
>5-20	42	330.25	7.86	58
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	362	714.70	1.97	78
				Five year period 1994-1998
0	40	0.00	0.00	0
>0-5	453	724.15	1.60	62
>5-25	311	4283.55	13.77	48
>25-100	186	6673.40	35.88	46
>100	0	0.00	0.00	0
Total	990	11681.10	11.80	48

Hybrid lognormal parameters for positive doses in 1998:
ρ: 0.1217
μ: -1.8402
σ^2: 2.4487
Sample size: 348
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

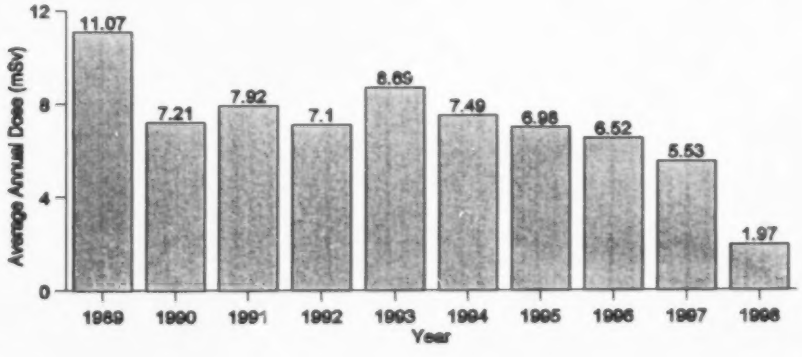


Table 4 (Cont'd)
Uranium Mine Underground Personnel

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Radon Progeny
				Year 1998
0	181	0.00	0.00	0
>0-1	117	46.10	0.39	87
>1-2	23	35.40	1.54	90
>2-5	16	45.05	2.82	74
>5-20	9	63.75	7.08	59
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	346	190.30	0.55	75
				Five year period 1994-1998
0	496	0.00	0.00	0
>0-5	442	454.10	1.03	45
>5-25	70	701.30	10.02	53
>25-100	4	140.20	35.05	62
>100	0	0.00	0.00	0
Total	1012	1295.60	1.28	51

Lognormal parameters for positive doses in 1998:
μ: -0.6017
σ^2: 1.5129
Sample size: 165
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998

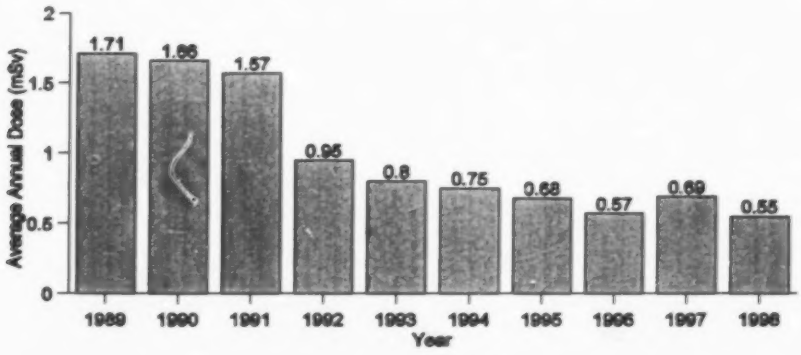
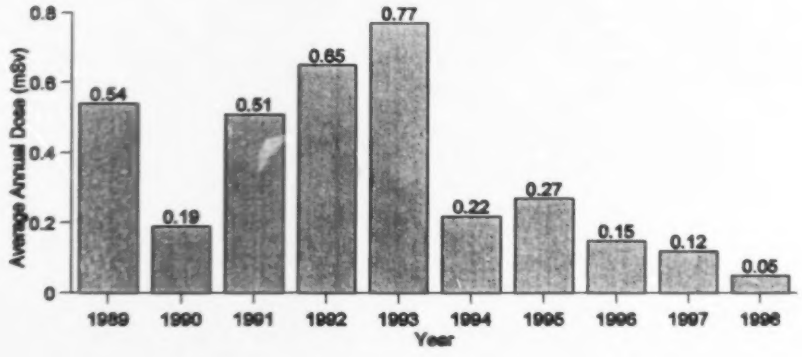


Table 4 (Cont'd)
Uranium Mine Visitor

Dose Interval (mSv)	Number of Workers	Collective Dose	Average Dose	% Radon Progeny
				Year 1998
0	199	0.00	0.00	0
>0-1	96	14.90	0.16	86
>1-2	0	0.00	0.00	0
>2-5	0	0.00	0.00	0
>5-20	0	0.00	0.00	0
>20-50	0	0.00	0.00	0
>50	0	0.00	0.00	0
Total	295	14.90	0.05	86
				Five year period 1994-1998
0	332	0.00	0.00	0
>0-5	391	162.85	0.42	50
>5-25	4	22.75	5.69	21
>25-100	0	0.00	0.00	0
>100	0	0.00	0.00	0
Total	727	185.60	0.26	46

Lognormal parameters for positive doses in 1998:
μ: -2.2589
σ^2: 0.6648
Sample size: 96
(See Appendix for explanation)

Histogram of average annual doses over ten year period 1989-1998



Appendix
The lognormal and hybrid lognormal distributions

The appendix explains how the data can be fitted to a statistical distribution, so that: (1) the sample of doses can be described by 3 or 4 quantities (the parameters of the distribution and sample size); and, (2) from these quantities, any dose statistic can be estimated, including any statistic not listed in this report, such as the 9-th decile.

Statistical distributions, such as the lognormal or hybrid lognormal distribution, are defined by a probability density function, containing a variable x, which in our case represents the occupational dose. This function is interpreted as follows:

The probability that a dose value lies between a and b equals

$$\int_a^b f(x)dx \quad ,$$

where f represents the probability density function.

Besides the variable (occupational dose) the probability density function contains a number of parameters, which determine the shape of the function. Only when the parameters have been specified is the statistical model for the occupational dose defined. Parameters are adjusted to fit the data.

The lognormal probability density function f is given by:

$$f(x: \mu,\sigma^2)=(1/x)(2\pi\sigma^2)^{-\frac{1}{2}} \exp(-\ln(x)-\mu)^2/2\sigma^2)$$

The hybrid lognormal probability density function f is given by:

$$f(x: \rho,\mu,\sigma^2)=(\rho+1/x)(2\pi\sigma^2)^{-\frac{1}{2}}\exp(-\ln(\rho x)+\rho x-\mu)^2/2\sigma^2)$$

In these functions, the quantities μ and σ^2 are parameters of the distribution. The hybrid lognormal distribution contains an extra parameter ρ. This distribution was introduced by Kumazawa[9] *et al*, for the purpose of describing a workforce that makes a sustained effort to stay below a regulatory limit. This distribution often gives a better fit than the lognormal distribution for certain high dose occupations, such as nuclear medicine workers. It is similar to a lognormal distribution for low doses and to a normal distribution for high doses.

If the parameters for the probability density function f are known, one can estimate any dose statistic. For example, the mean dose is estimated as

$$\int_0^\infty xf(x)dx$$

(since the dose values x are between 0 and infinity).

The variance of the dose is estimated as:

$$\int_0^\infty (x\text{-mean})^2 f(x)dx$$

and the standard deviation as the square root thereof.

The probability that a dose exceeds, for example, 50 mSv, is estimated as:

$$\int_{50}^\infty f(x)dx \quad .$$

The 95-th percentile is estimated as that dose value v for which:

$$\int_v^\infty f(x)dx = 95/100 \; .$$

The fraction of the collective dose due to doses exceeding 15 mSv is estimated as:

$$\frac{\int_{15}^\infty xf(x)dx}{\int_0^\infty xf(x)dx}$$

The parameters are determined from the actual dose data. They are chosen to give the best "fit" with the sample of observed data, for which purpose there exists a variety of methods. The parameters in Table 4 have been estimated with the Maximum Likelihood method. With this method, dose statistics can be estimated with the formulas given above, with the tabulated parameter values substituted for (ρ,) μ, and σ^2.

Software is available from the authors for the purpose of estimating occupational dose statistics and their confidence intervals. Since the lognormal and hybrid lognormal distribution do not apply to zero doses, as evident from the formulas of their probability density functions, the software will determine parameters based on positive doses only. Estimates for the total of all doses can be derived if the numbers of zero and positive doses in the sample are taken into account. For example, consider a sample in which half the doses are zero. If the parametric estimate is 2 mSv for the mean of the positive doses, then the estimate of the mean of all doses is 1 mSv. Or, if a parametric estimate for the 95-th percentile of all doses is needed, it is calculated as the estimate of the 90-th percentile for the positive doses.